Towards the Chalonge 16th Paris Cosmology Colloquium 2012:

HIGHLIGHTS and CONCLUSIONS
of the Chalonge 15th Paris Cosmology Colloquium 2011

FROM COLD DARK MATTER TO WARM DARK MATTER IN THE STANDARD MODEL OF THE UNIVERSE. THEORY AND OBSERVATIONS:

Ecole Internationale d'Astrophysique Daniel Chalonge
Observatoire de Paris
in the historic Perrault building, 20-22 July 2011.

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(Dated: February 27, 2013)

The Chalonge 15th Paris Cosmology Colloquium 2011 was held on 20-22 July in the historic Paris Observatory's Perrault building, in the Chalonge School spirit combining real cosmological/astrophysical data and hard theory predictive approach connected to them in the Warm Dark Matter Standard Model of the Universe: News and reviews from *Herschel*, QUIET, Atacama Cosmology Telescope (ACT), South Pole Telescole (SPT), *Planck*, PIXIE, the JWST, UFFO, KATRIN and MARE experiments; astrophysics, particle physics and nuclear physics warm dark matter (DM) searches and galactic observations, related theory and simulations, with the aim of synthesis, progress and clarification. Philippe Andre, Peter Biermann, Pasquale Blasi, Daniel Boyanovsky, Carlo Burigana, Hector de Vega, Joanna Dunkley, Gerry Gilmore, Alexander Kashlinsky, Alan Kogut, Anthony Lasenby, John Mather, Norma Sanchez, Alexei Smirnov, Sylvaine Turck-Chieze present here their highlights of the Colloquium. Ayuki Kamada and Sinziana Paduroiu present here their poster highlights. ΛWDM (Warm Dark Matter) is progressing impressively over ΛCDM whose galactic scale crisis and decline are staggering. The International School Daniel Chalonge issued an statement of strong support to the *James Webb Space Telescope* (JWST). The Daniel Chalonge Medal 2011 was awarded to John C. Mather, Science PI of the JWST. Summary and conclusions by H. J. de Vega, M. C. Falvella and N. G. Sanchez stress among other points:

(I) Data confirm primordial CMB gaussianity. Inflation effective theory predicts negligible primordial non-gaussianity, negligible scalar index running and a tensor to scalar ratio $r \sim 0.05 - 0.04$ at reach/border line of next CMB observations; the present data with this theory clearly prefer new inflation and the 'cosmic banana' region in the r vs n_s diagram; early fast-roll inflation is generic and provides the lowest multipoles depression and TE oscillations. Impressive new CMB high-l data were released from ACT and SPT, the CMB power spectrum displays now 9 clear peaks, various cosmic parameter degeneracies are now resolved, ACT observed primordial helium and detected the CMB lensing, CMB alone can provide now evidence for dark energy. WMAP7 Sunyaev-Zeldovich (SZ) amplitudes are smaller of 0.5-0.7 than expected with respect to X-ray models, relaxed and non-relaxed clusters need distinction; the *Planck* first released results did not found such SZ depression. The Primordial Inflation Explorer (PIXIE) is planned to test inflation and to robustly detect CMB tensor (B-mode) polarisation (primordial gravitational waves) to limit $r < 10^{-3}$ at more than 5 sigma. PIXIE also allows to test keV warm dark-matter and reionization. On the other hand, cluster peculiar flows of about $600 - 1000 \ km/sec$ and coherent length $\sim 750 \ Mpc$ seem to be measured and would require if confirmed a fast-roll inflationary explanation.

(II) Significant progresses are made in dSph galaxy observations: Very low star formation rates and very low baryonic feedback are found. Baryon feedback does not affect DM structure, CDM does not produce realistic galaxies with realistic feedback and star formation recipes. Very precise

kinematics of stars in dSph is probing directly DM density profiles: cusped profiles are excluded at the $95\% CL$. Cored (non cusped) DM halos and warm (keV scale mass) DM are strongly favored from theory and astrophysical observations, they naturally produce the observed small scale structures; keV sterile neutrinos of mass between 1 and 10 keV are the most serious candidates. Progresses in computing the distribution function for WDM sterile neutrinos as well as ΛWDM simulations with them were reported. Wimps (heavier than 1 GeV) are strongly disfavoured combining theory with galaxy observations. In addition, the observed cosmic ray positron and electron excesses are explained by natural astrophysical processes, while annihilating/decaying cold dark matter models are strongly disfavored. On the other hand, non-annihilating CDM wimps in the sun are excluded. The sun seismic model can be also used to constrain WDM (sterile neutrinos).

(III) *Herschel* remarkably observed a profusion of interstellar pc-scale filaments sharing a common width $\sim 0.1 pc$ and a critical mass per unit length $\sim 15\ M_\odot$/pc, above which they are gravitationally unstable. This filamentary structure is intimately connected to the cloud core formation process. Remarkably, the independently observed interstellar surface density (colum density) and galaxy surface density have almost the same universal value, irrespective of size and composition, morphology and system types.

Putting all together, evidence that ΛCDM does not work at small scales is staggering. ΛWDM simulations with 1 keV particles reproduce remarkable well the observations, the distribution of Milky Way satellites in the range above ~ 40 kpc, sizes of local minivoids and velocity functions. Overall, ΛWDM and keV scale DM particles deserve dedicated astronomical and laboratory experimental searches, theoretical work and simulations. KATRIN experiment in the future could perhaps adapt its set-up to look to keV scale sterile neutrinos. It will be a a fantastic discovery to detect dark matter in a beta decay. Photos of the Colloquium are included.

Contents

I. PURPOSE OF THE COLLOQUIUM, CONTEXT AND INTRODUCTION

The main aim of the series 'Paris Cosmology Colloquia', in the framework of the International School of Astrophysics **'Daniel Chalonge'**, is to put together real data : cosmological, astrophysical, particle physics, nuclear physics data, and hard theory predictive approach connected to them in the framework of the Standard Model of the Universe.

The Chalonge Paris Cosmology Colloquia bring together physicists, astrophysicists and astronomers from the world over. Each year these Colloquia are more attended and appreciated both by PhD students, post-docs, senior participants and lecturers. The format of the Colloquia is intended to act as a true working meeting and laboratory of ideas, and allow easy and fruitful mutual contacts and communication.

The discussion sessions are as important as the lectures themselves.

The **15th Paris Cosmology Colloquium 2011** was devoted to 'FROM COLD DARK MATTER TO WARM DARK MATTER IN THE STANDARD MODEL OF THE UNIVERSE: THEORY AND OBSERVATIONS'.

The Colloquium took place during three full days (Wednesday July 20, Thursday 21 and Friday July 22) at the parisian campus of Paris Observatory (HQ), in the historic Perrault building.

Never as in this period, the Golden Age of Cosmology, the major subjects of the Daniel Chalonge School were so timely and in full development: Recently, Warm (keV scale) Dark Matter (WDM) emerged impressively over CDM (Cold Dark Matter) as the leading Dark Matter candidate. Astronomical evidence that Cold Dark Matter (LambdaCDM) and its proposed tailored cures do not work at small scales is staggering. LambdaWDM solves naturally the problems of LambdaCDM and agrees remarkably well with the observations at small as well as large and cosmological scales. LambdaWDM numerical simulations naturally *agree* with observations at all scales, in contrast to LambdaCDM simulations which only agree at large scales.

In the context of the new Dark Matter situation represented by Warm (keV scale) Dark Matter which implies novelties in the astrophysical, cosmological and keV particle and nuclear physics context, this 15th Paris Colloquium 2011 was devoted to the LambdaWDM Standard Model of the Universe.

Strong **Support to the James Webb Space Telescope** (JWST) was provided during this Colloquium and a Statement of Support to the JWST from the Chalonge School was written and made public during the Open Session and largely advertised worldwide: after the Colloquium. See section IV devoted to the JWST Support in these Highlights.

An **Open Session** took place before the end of the Colloquium with two Lectures: The James Webb Space Telescope (JWST) by John Mather, Science PI of the JWST, and the Ultra-Fast Flash Observatory (UFFO) Pathfinder by George Smoot, both Nobel Laureats of physics and of the Daniel Chalonge Medal.

The **Daniel Chalonge Medal 2011** was awarded to John Mather during the Open Session of the Colloquium for his multiple achievements, COBE, and his brilliant activity in the JWST. See section V devoted to the Daniel Chalonge Medal 2011 in these Highlights.

The Main topics of this Colloquium included :

Observational and theoretical progress on the nature of dark matter : keV scale Warm Dark Matter.
Dark energy: cosmological constant: the quantum energy of the cosmological vacuum.

Large and small scale structure formation in agreement with observations at large scales and small (galactic) scales.

The ever increasing problems of LambdaCDM.

The emergence of Warm (keV scale) Dark Matter from theory and observations.

Neutrinos in astrophysics and cosmology.

The new serious dark matter candidate: Sterile neutrinos at the keV scale.

Neutrino mass bounds from cosmological data and from high precision beta decay experiments.

The analysis of the CMB+LSS+SN data with the effective (Ginsburg-Landau) effective theory of inflation: New

Inflation (double well inflaton potential) strongly favored by the CMB + LSS + SN data.
The presence of the lower bound for the primordial gravitons (non vanishing tensor to scalar ratio r) with the present

CMB + LSS + SN data. CMB polarization and forecasts for Planck.
CMB measurements. The Atacama Cosmology Telescope. The *Planck* mission, its science perspectives and results.

Recent *Herschel* results from the ISM to the IMF.

Recent Herschel-SPIRE Legacy Survey (HSLS) results for cosmology and dark Matter.

The James Webb Space Telescope: mission and science

Context, CDM Crisis and CDM Decline:

On large cosmological scales, CDM agrees in general with observations but CDM does not agree with observations on galaxy scales and small scales. Over most of twenty years, increasing number of cyclic arguments and ad-hoc mechanisms or recipes were-and continue to be- introduced in the CDM galaxy scale simulations, in trying to deal with the CDM small scale crisis: Cusped profiles and overabundance of substructures are predicted by CDM. Too many satellites are predicted by CDM simulations while cored profiles and no such overabundant substructures are seen by astronomical observations. Galaxy formation within CDM is increasingly confusing and in despite of the proposed cures, does not agree with galaxy observations.

On the CDM particle physics side, the situation is no less critical: So far, all the dedicated experimental searches after most of twenty years to find the theoretically proposed CDM particle candidate (WIMP) have failed. The CDM indirect searches (invoking CDM annihilation) to explain cosmic ray positron excesses, are in crisis as well, as wimp annihilation models are plagued with growing tailoring or fine tuning, and in any case, such cosmic rays excesses are well explained and reproduced by natural astrophysical process and sources. The so-called and repeatedly invoked 'wimp miracle' is nothing but been able to solve one equation with three unknowns (mass, decoupling temperature, and annihilation cross section) within wimp models theoretically motivated by SUSY model building twenty years ago (at that time those models were fashionable and believed for many proposals).

After more than twenty years -and as often in big-sized science-, CDM research has by now its own internal inertia: growing simulations involve large super-computers and large and long-time planned experiments, huge number of people, (and huge budgets); one should not be surprised in principle, if a fast strategic change would not yet operate in the CDM and wimp research, although its interest would progressively decline.

In contrast to the CDM situation, the WDM research situation is progressing fast, the subject is new and WDM essentially *works*, naturally reproducing the observations over all the scales, small as well as large and cosmological scales (ΛWDM). WDM became a hot topic and the subject of many doctoral and post-doctoral researches.

Format and Exhibitions

All Lectures are plenary and followed by a discussion. Enough time is provided to the discussions.

Informations of the Colloquium are available on

http://www.chalonge.obspm.fr/colloque2011.html

Informations on the previous Paris Cosmology Colloquia and on the Chalonge school events are available at

http://chalonge.obspm.fr
(lecturers, lists of participants, lecture files and photos during the Colloquia).

This Paris Chalonge Colloquia series started in 1994 at the Observatoire de Paris. The series cover selected topics of high current interest in the interplay between cosmology, astrophysics and fundamental physics. The purpose of this series is an updated understanding, from a fundamental, conceptual and unifying view, of the progress and current problems in the early universe, cosmic microwave background radiation, large and small scale structure and neutrinos in astrophysics and the interplay between them. Emphasis is given to the mutual impact of fundamental physics, astrophysics and cosmology, both at theoretical and experimental -or observational- levels.

Deep understanding, clarification, synthesis, a careful interdisciplinarity within a fundamental physics and unifying approach, are goals of this series of Colloquia.

Sessions leave enough time for private discussions and to enjoy the beautiful parisian campus of Observatoire de Paris (built on orders from Colbert and to plans by Claude Perrault from 1667 to 1672).

Sessions take place in the Cassini Hall, on the meridean of Paris, in 'Salle du Conseil' (Council Room) under the portraits of Laplace, Le Verrier, Lalande, Arago, Delambre and Louis XIV, and in the 'Grande Galerie' (the Great Gallery), in the historic Perrault building ('Bâtiment Perrault') of Observatoire de Paris HQ.

An **Exhibition** at the 'Grand Galerie' (Great Gallery) and "Salle Cassini" (Cassini Hall) retraced the 20 years of activity of the Chalonge School and **"The Golden Days" in 'Astrofundamental Physics': The Construction of the Standard Model Of the Universe**, as well as **'The World High Altitude Observatories Network: World Cultural and Scientific Heritage'**.

The books and proceedings of the School since its creation, as well as historic Daniel Chalonge material, instruments and the Daniel Chalonge Medal were on exhibition at the Grande Galerie.

The exhibitions were prepared by Maria Cristina Falvella, Alba Zanini, François Sevre, Nicole Letourneur and Norma G. Sanchez.

Photos and Images by : Kathleen Blumenfeld, Letterio Pomara, Jean Mouette, François Sevre, François Colas, Nadia Blumenfeld, Gerard Servajean, Sylvain Cnudde, graphic design by Emmanuel Vergnaud.

After the Colloquium, a visit of the Perrault building took place guided by Professor Suzanne Debarbat

More information on the Colloquia of this series can be found in the Proceedings (H.J. de Vega and N. Sanchez, Editors) published by World Scientific Co. since 1994 and by Observatoire de Paris, and the Chalonge School Courses published by World Scientific Co and by Kluwer Publ Co. since 1991.

We address here the recent turning point in the research of Dark Matter represented by Warm Dark Matter (WDM) putting together astrophysical, cosmological, particle and nuclear physics WDM, astronomical observations, theory and WDM numerical simulations which naturally reproduce the observations, as well as the experimental search for the WDM particle candidates (sterile neutrinos).

This 15th Paris Chalonge Colloquium 2011 enlarges, strengghs and unifies with new topics, lecturers and deep discussions the issues discussed and pre-viewed in the Warm Dark Matter Chalonge Meudon Workshop 2011 in June 2011.

The Highlights and Conclusions of the 14th Paris Chalonge Colloquium 2010 and of the Chalonge Meudon Workshop 2011 are a useful and complementary introduction to these Highlights and can be read with benefit, they are available at:

http://arxiv.org/abs/1009.3494

http://arxiv.org/abs/1109.3187

Summary and Conclusions:

This 15th Paris Colloquium 2011 addressed the last progresses made in the STANDARD MODEL OF THE UNIVERSE-WARM DARK MATTER with both theory and observations. In the tradition of the Chalonge School, an effort of clarification and synthesis is made by combining in a conceptual framework, theory, analytical, observational and numerical simulation results which reproduce observations, both in astrophysics and particle and nuclear physics, keV sterile neutrinos being today the more serious candidates for Dark Matter.

The subject have been approached in a fourfold coherent way:

(I) Conceptual context, the standard cosmological model includes inflation

(II) CMB observations and astronomical observations, cosmological, large, intermediate and small galactic scales, and interstellar medium observations, linked to structure formation at the different scales.

(III) WDM theory, models and WDM numerical simulations which reproduce observations at large and small (galactic) scales.

(IV) WDM particle candidates, keV sterile neutrinos: particle models and astrophysical constraints on them

Philippe Andre, Peter Biermann, Pasquale Blasi, Daniel Boyanovsky, Carlo Burigana, Hector de Vega, Joanna Dunkley, Gerry Gilmore, Ayuki Kamada, Alexander Kashlinsky, Alan Kogut, Anthony Lasenby, John Mather, Sinziana Paduroiu, Norma Sanchez, Alexei Smirnov, Sylvaine Turck-Chieze present here their highlights of the Colloquium.

Summary and conclusions are presented at the end by H. J. de Vega, M. C. Falvella and N. G. Sanchez in three subsections:

A. General view and clarifying remarks.

B. Conclusions.

C. The present context and future in the Dark Matter research and Galaxy formation

The Summary of the Conclussions stress among other points :

(I) Data confirm primordial CMB gaussianity. Inflation effective theory predicts negligible primordial non-gaussianity, negligible scalar index running and a tensor to scalar ratio $r \sim 0.05 - 0.04$ at reach/border line of next CMB observations; the present data with this theory clearly prefer new inflation and the 'cosmic banana' region in the r vs n_s diagram; early fast-roll inflation is generic and provides the lowest multipoles depression and TE oscillations. Impressive new CMB high-l data were released from ACT and SPT, the CMB power spectrum displays now 9 clear peaks, various cosmic parameter degeneracies are now resolved, ACT observed primordial helium and detected the CMB lensing, CMB alone can provide now evidence for dark energy. WMAP7 Sunyaev-Zeldovich (SZ) amplitudes are smaller of 0.5-0.7 than expected with respect to X-ray models, relaxed and non-relaxed clusters need distinction; the *Planck* first released results did not found such SZ depression. The Primordial Inflation Explorer (PIXIE) is planned to test inflation and to robustly detect CMB tensor (B-mode) polarisation (primordial gravitational waves) to limit $r < 10^{-3}$ at more than 5 sigma. PIXIE also allows to test keV warm dark-matter and reionization. On the other hand, cluster peculiar flows of about $600 - 1000 km/sec$ and coherent length $\sim 750 Mpc$ seem to be measured and would require if confirmed a fast-roll inflationary explanation.

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structure is intimately connected to the cloud core formation process. Remarkably, the independently observed inter-stellar surface density (colum density) and galaxy surface density have almost the same universal value, irrespective of size and composition, morphology and system types.

Putting all together, evidence that ΛCDM does not work at small scales is staggering. Impressive evidence points that DM particles have a mass in the keV scale and that those keV scale particles naturally produce the small scale structures observed in galaxies. Wimps (DM particles heavier than 1 GeV) are strongly disfavoured combining theory with galaxy astronomical observations. keV scale sterile neutrinos are the most serious DM candidates and deserve dedicated experimental searchs and simulations. Astrophysical constraints including Lyman alpha bounds put the sterile neutrinos mass in the range $1 < m < 13$ keV. ΛWDM simulations with 1 keV particles reproduce remarkable well the observations, the distribution of Milky Way satellites in the range above ~ 40 kpc, sizes of local minivoids and velocity functions. Overall, ΛWDM and keV scale DM particles deserve dedicated astronomical and laboratory experimental searches, theoretical work and simulations. MARE -and hopefully an adapted KATRIN- experiment could provide a sterile neutrino signal. The experimental search for this serious DM candidate appears urgent and important: It will be a fantastic discovery to detect dark matter in a beta decay.

There is an encouraging and formidable WDM work to perform ahead us, these highlights point some of the directions where to put the effort.

We want to express our grateful thanks to all the sponsors of the Colloquium, to all the lecturers for their excellent and polished presentations, to all the lecturers and participants for their active participation and their contribution to the outstanding discussions and lively atmosphere, to the assistants, secretaries and all collaborators of the Chalonge School, who made this event so harmonious, wonderful and successful .

We are pleased to give you appointment at the next Colloquium of this series:

The 16th Paris Cosmology Colloquium 2012 devoted to

THE NEW STANDARD MODEL OF THE UNIVERSE: LAMBDA WARM DARK MATTER (ΛWDM) THEORY AND OBSERVATIONS

Observatoire de Paris, historic Perrault building, 25, 26, 27 JULY 2012.

http://www.chalonge.obspm.fr/colloque2012.html

With Compliments and kind regards,

Hector J de Vega, Maria Cristina Falvella, Norma G Sanchez

FIG. 1: Photo of the Group

II. PROGRAMME AND LECTURERS

- **Philippe ANDRE**(CEA/DSM/IRFU Saclay Orme des Merisiers, Gif-sur-Yvette, France)
  From the Filamentary Structure of the ISM to Prestellar Cores to the Stellar IMF: Recent Herschel Results

- **Peter BIERMANN** (MPI-Bonn, Germany & Univ of Alabama, Tuscaloosa, USA)
  Astrophysical Warm Dark Matter

- **Pasquale BLASI** (INAF/Arcetri Astrophysical Observatory, Firenze, Italy)
  Astrophysical Origin of the Positron Excess in Cosmic Rays

- **Daniel BOYANOVSKY** (Univ. of Pittsburgh, Dept of Physics and Astronomy, USA)
  Sterile Neutrinos as Warm Dark Matter Candidates.

- **Carlo BURIGANA & Reno MANDOLESI** (INAF-IASF, Bologna, Italy)
  The Planck satellite: from the first astrophysical results to cosmological promises

- **Asantha COORAY** (University of California,Irvine, USA)
  The Herschel-SPIRE Legacy Survey (HSLS): Cosmological and Dark Matter Implications.

- **Hector J. DE VEGA** (CNRS LPTHE Univ de Paris VI, France)
  The Standard Model of the Universe: The Effective Theory of Inflation. Warm Dark Matter from theory and galaxy observations.

- **Joanna DUNKLEY** (Oxford Univ, Astrophysics, UK)
  Cosmological Implications of the Atacama Cosmology Telescope Results

FIG. 2: Poster of the 14th Paris Cosmology Colloquium 2010

- **Gerard F. GILMORE** (Institute of Astronomy, Cambridge University, UK)
  Observational Properties of Dark Matter on Small Astrophysical Scales.

- **Alexander KASHLINSKY** (NASA Goddard Space Flight Center, Greenbelt, MD, USA)
  Measuring Large Scale Flows of X-ray Luminous Galaxy Clusters

- **Alan KOGUT** (NASA Godard Space Flight Center, Greenbelt, MD, USA)
  Testing the Standard Model with the Primordial Inflation Explorer

- **Anthony N. LASENBY** (Cavendish Laboratory, Cambridge, UK)
  The CMB in the Standard Model of the Universe: A Status Report

- **Manfred LINDNER** (Max Planck Institut fr Kernphysik, Heidelberg, Germany)
  keV Sterile Neutrinos as Dark Matter

- **John C.MATHER** (NASA Goddard Space Flight Center, Greenbelt, MD, USA)
  Special Lecture: The James Webb Space Telescope

- **Félix MIRABEL** (CEA-Saclay, France & IAFE-Buenos Aires, Argentina)
  Astrophysical Black Holes and the Re-ionization of the Universe

- **Norma G. SANCHEZ** (CNRS LERMA Observatoire de Paris, France)
  The primordial banana of the Universe and the graviton/scalar ratio from WMAP to Planck. Warm Dark Matter and Galaxy properties from primordial fluctuations and observations.

- **Alexei SMIRNOV** (Abdus Salam ICTP,Trieste, Italy)
  Status of the Theory of Neutrino Masses and Mixings

- **George SMOOT** (BCCP LBL Berkeley,IEU Seoul, Univ Paris Diderot USA)
  The Standard Model of the Universe

- **Sylvaine TURCK-CHIEZE** (SAp/IRFU/CEA Saclay, Gif sur Yvette, France)
  Helioseismology and Dark Matter

- **Christian WEINHEIMER** (Institut für Kernphysik Universität Münster, Münster, Germany)
  Absolute Scale of the Neutrino Mass and the Search for Neutrinoless Double Beta Decay.

III. POSTERS AND PRESENTATIONS

- **Ayuki KAMADA** (IPMU, Institute for the Physics and Mathematics of the Universe,Tokyo,Japan) keV-mass sterile neutrino dark matter and the structure of galactic haloes

- **Sinziana PADUROIU, Observatoire de Geneve, Switzerland** Numerical simulations with Warm Dark Matter: The effects of free streaming on Warm Dark Matter haloes of Galaxies

IV. SUPPORT TO THE JAMES WEBB SPACE TELESCOPE

Ecole Internationale d'Astrophysique Daniel Chalonge

CHALONGE SCHOOL STATEMENT OF SUPPORT TO THE JAMES WEBB SPACE TELESCOPE

On 22th July 2011, during the 15th Paris Cosmology Colloquium 2011 of the International School of Astrophysics Daniel Chalonge at Paris Observatory, **Dr. John Mather**, Nobel Laureate 2006 for the outstanding results of the NASA COBE satellite, brilliantly **presented the NASA Program James Webb Space Telescope (JWST)**, the large infrared-optimized space telescope planned to operate from 2018 as the best successor for the Hubble and Spitzer Space Telescopes, with an ambitious scientific programme which ranges from the early universe, first galaxies formation, first light and reionization, star formation, to the protoplanetary and planetary systems and the origins of life. These subjects **represent the current frontier of knowledge in modern astrophysics and astronomy and the most interesting new programs in the field**.

One of the aims of the Chalonge School is to bring the attention into the new programs which will produce a clearer and deeper understanding of the Universe with both innovative experiments and theory. During the 15th Paris Cosmology Colloquium 2011, the Chalonge School has made the following statement in support to the James Webb Space Telescope:

The Ecole Internationale Daniel Chalonge considers that JWST is an exceptional opportunity for the future of astrophysics and astronomy worldwide. The Ecole Internationale Daniel Chalonge recognizes the outstanding scientific value of the JWST project, its potentiality and worldwide impact and strongly supports its development and successfull completion.

Norma G. Sanchez (1) , Hctor J. de Vega (2), Maria Cristina Falvella (3) , Alba Zanini (4)

(1) Director of the International Astrophysics Daniel Chalonge School, CNRS, Observatoire de Paris, France. (2) CNRS, University Pierre & Marie Curie, Paris, France. (3) Italian Space Agency HQ, Rome, Italy. (4) Istituto Nazionale di Fisica Nucleare (INFN), Turin, Italy.

Links to the Statement and to the JWST :

http://chalonge.obspm.fr/jwst.pdf

JWST Community Support from the 15th paris Cosmology Colloquium Chalonge 2011

http://www.aura-astronomy.org/news/2011/jwstChalonge.pdf

Information on The James Webb Space Telescope:

http://www.jwst.nasa.gov/

http://www.chalonge.obspm.fr/Paris11Mather.pdf

Support to the JWST among the world:

Association of Universities for the Research in Astronomy (AURA):

JWST AURA Resource Center

http://www.aura-astronomy.org/news/jwst.asp

V.   AWARD OF THE DANIEL CHALONGE MEDAL 2011

The Daniel Chalonge Medal 2011 has been awarded to **Dr John C. MATHER**.

The International Astrophysics School Daniel Chalonge has awarded the Daniel Chalonge Medal 2011
to Dr. John C. Mather, Nobel prize of Physics 2006 for the outstanding results of the COBE satellite, and present Senior Project Scientist for the James Webb Space Telescope.

Dr. John C. Mather is a Senior Astrophysicist in the Observational Cosmology Laboratory at the NASA Goddard Space Flight Center (College Park -Maryland, USA).

The medal was awarded to John Mather for his huge contribution to modern cosmology, in particular for his outstanding effort in promoting and leading key missions for the study of the Universe, as the COBE satellite and now the JWST, deeply discussed in the frame of the Chalonge School and the training and formation of young physicists and astrophysicists.

John Mather brilliantly presented the JWST Program , the large infrared-optimized space telescope planned to operate from 2018 as the best successor for the Hubble and Spitzer Space Telescopes. The Chalonge Medal represents too a warm aknowledgement and support to Dr. John Mather present and future activities in the JWST.

John Mather also contributed to ground observation programs leading advisory and working groups for the National Academy of Sciences, NASA, and the NSF (for the ALMA, the Atacama Large Millimeter Array, and for the CARA, the Center for Astrophysical Research in the Antarctic).

As Senior Project Scientist for the JWST, John Mather successfully leads the science team, and represents the scientific interests within the project management.

The medal was presented to John Mather on 22th July 2011 during the Open Session of the 15th Paris Cosmology Colloquium 2011 at the Observatoire de Paris HQ (historic Perrault building) in the Cassini Hall, on the meridian of Paris, which was attended by about hundred participants from the world over, among them three laureate of the Chalonge Medal: George Smoot, Nobel laurate of physics, Anthony Lasenby and Peter Biermann.

The list of the awarded Chalonge Medals is the following:

- 1991: Subramanyan Chandrasekhar, Nobel prize of physics.
- 1992: Bruno Pontecorvo.
- 2006: George Smoot, Nobel prize of physics.
- 2007: Carlos Frenk.
- 2008: Anthony Lasenby.
- 2008: Bernard Sadoulet.
- 2009: Peter Biermann.
- 2011: John Mather, Nobel prize of physics.

The Chalonge Medal, coined exclusively for the Chalonge School by the prestigious Hotel de la Monnaie de Paris (the French Mint), is a surprise award and only eight Chalonge medals have been awarded in the 20 year school history.

The Medal aknowledges science with great intellectual endeavour and a human face. True and healthy science. Outstanding gentleperson scientists. Scientists recipients of the Daniel Chalonge Medal are Ambassadors of the School.

See the announcement, full history, photo gallery and links at: http://chalonge.obspm.fr

The Daniel Chalonge Medal 2011 http://chalonge.obspm.fr/MedalChalonge2011.pdf

Mather's Open Lecture on the JWST :

http://www.chalonge.obspm.fr/Paris11Mather.pdf

Photo Gallery:

http://chalonge.obspm.fr/albumopensession2011/index.html

Archives Daniel Daniel Chalonge: http://chalonge.obspm.fr/ArchivesDanielChalonge.html

VI.   HIGHLIGHTS BY THE LECTURERS

More informations on the Colloquium Lectures are at:

http://www.chalonge.obspm.fr/colloque2011.html

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From the filamentary structure of the ISM to prestellar cores to the IMF: Recent *Herschel* results

The immediate observational objective of the *Herschel* Gould Belt survey ([1], [2]) is to image the bulk of nearby ($d \sim 500$ pc) molecular clouds at 6 wavelengths between 70 μm and 500 μm. This will provide complete samples of prestellar cores and "Class 0" protostars with well characterized luminosities, temperatures, and density profiles, as well as robust core mass functions and protostar luminosity functions, in a variety of star-forming environments. The main scientific goal is to elucidate the physical mechanisms responsible for the formation of prestellar cores out of the diffuse interstellar medium (ISM), crucial for understanding the origin of the stellar initial mass function (IMF). Briefly, the first images from the Gould Belt survey have revealed a profusion of parsec-scale filaments in nearby molecular clouds and suggested an intimate connection between the filamentary structure of the ISM and the formation process of dense cloud cores ([2], [3] – see Fig. 1). Remarkably, filaments are omnipresent even in unbound, non-star-forming complexes such as the Polaris translucent cloud ([4], [5]), and all appear to share a common (FWHM) width ~ 0.1pc ([6]). Moreover, in active star-forming regions such as the Aquila Rift cloud ([7], [8]), most of the prestellar cores identified with *Herschel* are located within gravitationally unstable filaments for which the mass per unit length exceeds the critical value ([9]) $M_{\text{line,crit}} = 2\,c_s^2/G \sim 15\,M_\odot$/pc, where $c_s \sim 0.2$ km/s is the isothermal sound speed for $T \sim 10$ K. These findings led us ([2]) to favor a scenario according to which core formation occurs in two main steps. First, large-scale magneto-hydrodynamic (MHD) turbulence generates an intricate network of filaments in the ISM (cf. [10]); second, the densest filaments fragment into prestellar cores by gravitational instability (cf. [11]). This scenario provides an *explanation* of the star formation threshold at a gas surface density $\Sigma_{\text{gas}}^{\text{th}} \sim 130\,M_\odot\,\text{pc}^{-2}$ found in recent infrared studies of the star formation rate in both Galactic and extragalactic cloud complexes (e.g. [12]): Given the typical ~ 0.1 pc width of interstellar filaments ([6]), the threshold $\Sigma_{\text{gas}}^{\text{th}}$ corresponds to within a factor of < 2 to the critical mass per unit length $M_{\text{line,crit}}$ above which gas filaments at $T \sim 10$ K are gravitationally unstable.
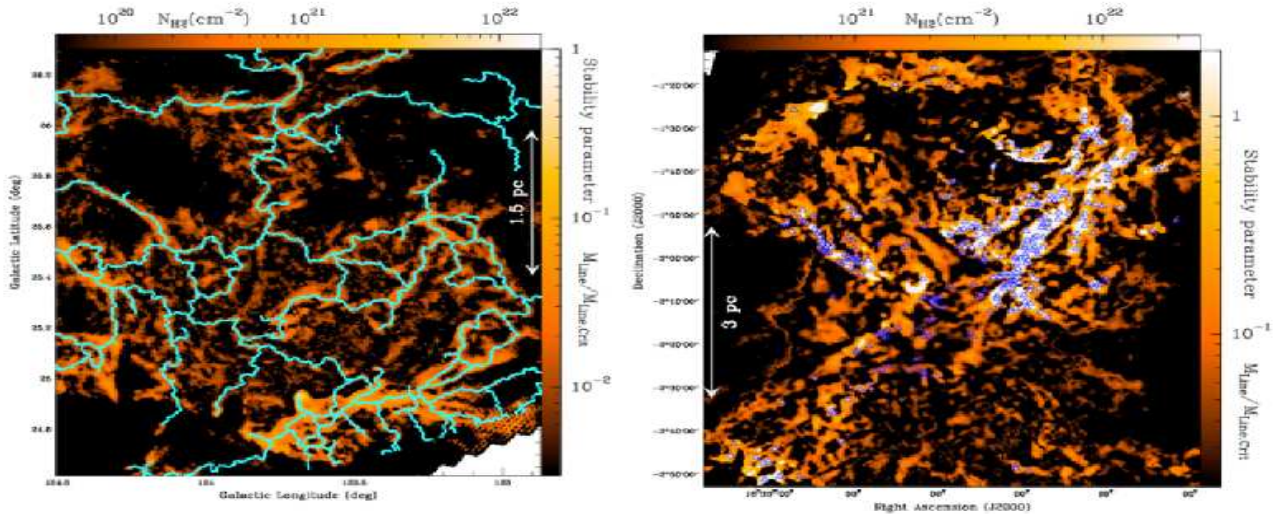
Fig. 1: Column density maps of two fields in Polaris (left) and Aquila (right) derived from *Herschel* data ([2]). The contrast of the filaments has been enhanced using a curvelet transform (cf. [3]). The skeleton of the filament network identified in Polaris with the DisPerSE algorithm ([13]) is shown in light blue in the left panel. Given the typical width ~ 0.1 pc of the filaments ([6]), these maps are equivalent to *maps of the mass per unit length along the filaments.* The areas where the filaments have a mass per unit length larger than half the critical value $2\, c_s^2/G$ and are thus likely gravitationally unstable have been highlighted in white. The bound prestellar cores identified by [7] in Aquila are shown as small triangles in the right panel; there are no bound cores in Polaris. Note the good correspondence between the spatial distribution of prestellar cores and the regions where the filaments are unstable to gravitational collapse. (Adapted from [2].)

Our *Herschel* first results also confirm the existence of a close relationship between the prestellar core mass function (CMF) and the stellar IMF ([2], [7] – see Fig. 2). Interestingly, the peak of the prestellar CMF at $\sim 0.6\,M_\odot$ as observed in the Aquila complex (cf. Fig. 2b) corresponds to the Jeans or Bonnor-Ebert mass $M_{\rm BE} \sim 0.6\,M_\odot \times (T/10\,{\rm K})^2 \times \left(\Sigma/150\,M_\odot\,{\rm pc}^{-2}\right)^{-1}$ within marginally critical filaments with $M_{\rm line} \approx M_{\rm line,crit} \sim 15\,M_\odot/{\rm pc}$ and surface densities $\Sigma \approx \Sigma_{\rm gas}^{\rm crit} \sim 150\,M_\odot\,{\rm pc}^{-2}$. Likewise, the median spacing ~ 0.08 pc observed between the prestellar cores of Aquila roughly matches the thermal Jeans length within marginally critical filaments. This is consistent with the idea that gravitational fragmentation is the dominant physical mechanism generating prestellar cores within the filaments. Furthermore, a typical prestellar core mass of $\sim 0.6\,M_\odot$ translates into a characteristic star or stellar system mass of $\sim 0.2\,M_\odot$, assuming a local star formation efficiency $\epsilon_{\rm core} \sim 30\%$ at the level of individual cores ([14]). Therefore, our *Herschel* findings strongly support Larson's interpretation ([15]) of the peak of the IMF in terms of the typical Jeans mass in star-forming clouds. Overall, our results suggest that the gravitational fragmentation of supercritical filaments produces the prestellar CMF which, in turn, accounts for the log-normal "base" of the IMF. It remains to be seen, however, whether the bottom end of the IMF and the Salpeter power-law slope at the high-mass end can be explained by the same mechanism.
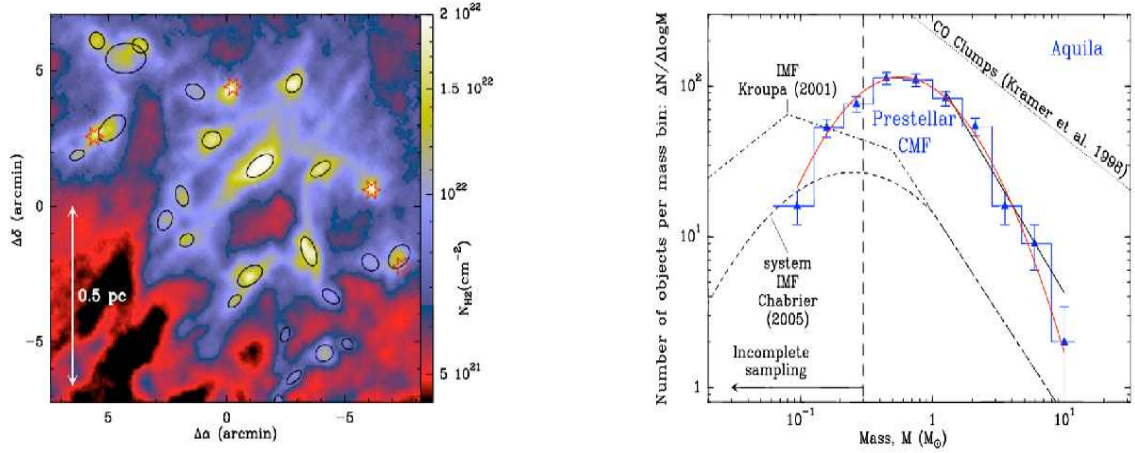
Fig. 2: **Left:** Close-up column density image of a small subfield in the Aquila Rift complex showing several candidate prestellar cores identified with *Herschel* (adpated from [7]). The black ellipses mark the major and minor FWHM sizes determined for these cores at $\lambda = 250\,\mu$m by the source extraction algorithm *getsources* ([3]). Four protostellar cores are also shown by red stars. **Right:** Core mass function (histogram with error bars) of the 541 candidate prestellar cores identified with *Herschel* in Aquila ([2], [7]). The IMF of single stars (corrected for binaries – e.g. [16]), the IMF of multiple systems (e.g. [17]), and the typical mass spectrum of CO clumps (e.g. [18]) are shown for comparison. A log-normal fit to the observed CMF is superimposed; it peaks at $\sim 0.6\,M_\odot$, which corresponds to the Jeans mass within marginally critical filaments at $T \sim 10$ K.

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ASTROPHYSICS OF WARM DARK MATTER

Dark matter has been first detected 1933 (Zwicky [1]) and basically behaves like a non-EM-interacting gravitational gas of particles. From particle physics Supersymmetry suggests with an elegant argument that there should be a lightest supersymmetric particle, which is a dark matter candidate, possibly visible via decay in odd properties of energetic particles and photons: We have discovered i) an upturn in the CR-positron fraction, ii) an upturn in the CR-electron spectrum, iii) a flat radio emission component near the Galactic Center (WMAP haze), iv) a corresponding IC component in gamma rays (Fermi haze and Fermi bubble), v) the 511 keV annihilation line also near the Galactic Center (Integral), and most recently, vi) an upturn in the CR-spectra of all elements from Helium (CREAM), with a hint of an upturn for Hydrogen, vii) A flat γ-spectrum at the Galactic Center (Fermi), and viii) have the complete cosmic ray spectrum available through 10^{15} to 10^{18} eV (KASCADE-Grande).

All the above features can be quantitatively explained with the action of cosmic rays accelerated in the magnetic winds of very massive stars, when they explode (Biermann et al., [2 - 6]): this work is based on predictions from 1993 ([7 - 11]); this approach is older and simpler than adding WR-star supernova CR-contributions with pulsar wind nebula CR-contributions, and also simpler than using the decay of a postulated particle. This concept gives an explanation for the cosmic ray spectrum as Galactic plus one extragalactic source, Cen A ([4,6]). The data do not require any extra source population below the MWBG induced turnoff - commonly referred to as the GZK-limit: [12,13]. This is possible, since the magnetic horizon appears to be quite small (consistent with the cosmological MHD simulations of Ryu et al. [14,15]). It also entails that Cen A is our highest energy physics laboratory accessible to direct observations of charged particles. All this allows to go back to galaxy data to derive the key properties of the dark matter particle: Work by [16 - 23] clearly points to a keV particle. A right-handed neutrino is a Fermion candidate to be this particle (e.g. [24 - 31]; also see [32,33]: This particle has the advantage to allow star formation very early, near redshift 80, and so also allows the formation of supermassive black holes: they possibly formed out of agglomerating massive stars, in the gravitational potential well of the first DM clumps, whose mass in turn is determined by the properties of the DM particle. Black holes in turn also merge, but in this manner start their mergers at masses of a few million solar masses, about ten percent of the baryonic mass inside the initial dark matter clumps. This readily explains the supermassive black hole mass function ([34]). The formation of the first super-massive stars might be detectable among the point-source contributions to the fluctuations of the MWBG at very high wave-number (Atacama); their contribution is independent of redshift. The corresponding gravitational waves are not constrained by any existing limit, and could have given a substantial energy contribution at high redshift. Our conclusion is that a right-handed neutrino of a mass of a few keV is the most interesting candidate to constitute dark matter.

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Warm Dark Matter at small scales.

The current 'standard model of cosmology' ΛCDM correctly describes large scale structure but evidence has been emerging that suggest several problems with this paradigm at *small scales* [1]. The small scale problems may be ameliorated by invoking a Warm Dark Matter candidate in the form of a particle with a mass in the $\sim$ keV range [2]. A sterile neutrino, namely a neutrino that does not feature standard model weak interactions is a suitable candidate [3]. Warm Dark Matter particles feature a non-vanishing velocity dispersion which leads to a cutoff in the matter power spectrum as a consequence of free streaming. The essential ingredient is the distribution function of the WDM candidate: $f_0(p) + F_1(\vec{p}, \vec{k}, \eta)$ where $f_0(p)$ is the unperturbed distribution function which is a solution of the collisionless Boltzmann equation in absence of gravitational perturbations and F_1 is a solution of the (linearized) Boltzmann equation with gravitational perturbations. Moments of f_0 determine the WDM abundance and the phase space density which provide upper and lower bounds on the mass [2] Reference [4] provide a semi-analytic method to obtain the transfer function and power spectra for arbitrary f_0. A WDM particle that decouples from the cosmological plasma when it is ultrarelativistic has three distinct stages of evolution: i) during the radiation dominated stage when the particle is ultrarelativistic, ii) radiation dominated stage when the particle is non-relativistic, iii) matter dominated stage. In stages i) and ii) gravitational perturbations are dominated by the radiation fluid, while in stage iii) the Boltzmann equation becomes a self-consistent integral-differential equation via Poisson's equation. The solution of the Boltzmann equation during stages i) and ii) yield the initial conditions on the distribution function for stage iii). Sterile neutrinos produced non-resonantly via two different mechanisms: mixing with active neutrinos and from the decay of scalar or vector bosons near the electroweak scale yield very different distribution functions. The power spectra for these species is obtained and compared in ref. [4], two noteworthy features emerge: i) a quasidegeneracy between the distribution function and the mass of the particle: a less massive WDM candidate with a distribution function that favors low momenta features a similar power spectrum as a more massive particle but with a near thermal distribution function, ii) the emergence of warm dark matter oscillations at scales of the order of the free streaming scale. The first feature suggests that constraints on the mass from the Lyman-α must be taken with a caveat since a reliable assessment requires knowledge of the distribution function, and the second feature suggests that typical fits to the power spectra in terms of power laws cannot reliable describe small scales. Non-vanishing velocity dispersion and free streaming lead to a redshift dependence of the matter and velocity power spectra which affects peculiar velocities and suggests that using the $z = 0$ power spectra for N-body simulations with initial conditions at large z incur in substantial errors underestimating the power spectrum of peculiar velocities. For details see [4]

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The *Planck* satellite: from the first astrophysical results to cosmological promises

At the date of this Conference, the *Planck* cosmic microwave background (CMB) anisotropy probe, launched into space on 14 May 2009, accumulated $\simeq$ 23.5 months of data, corresponding to about four complete sky surveys. The spacecraft will continue to operate until the consumption of the cryogenic liquids on January 2012 with its two instruments, the High Frequency Instrument (HFI), based on bolometers working between 100 and 857 GHz, and the Low Frequency Instrument (LFI), based on radiometers working between 30 and 70 GHz. A further 12 months extension has been approved for observations with LFI only, cooled down with the cryogenic system provided by HFI. A summary of the *Planck* performance is provided in Table I. *Planck* is sensitive to linear polarisation up to 353 GHz.

TABLE I: *Planck* performances. The average sensitivity, δT/T, per FWHM^2 resolution element (FWHM is reported in arcmin) is given in CMB temperature units (i.e. equivalent thermodynamic temperature) for 28 months of integration. The white noise (per frequency channel for LFI and per detector for HFI) in 1 sec of integration (NET, in μK $\cdot\sqrt{s}$) is also given in CMB temperature units. The other used acronyms are: DT = detector technology, N of R (or B) = number of radiometers (or bolometers), EB = effective bandwidth (in GHz). Adapted from [1,2].

LFI				HFI		
Frequency (GHz)	30	44	70			
InP DT	MIC	MIC	MMIC	Frequency (GHz)	100	143
FWHM	33.34	26.81	13.03	FWHM in T (P)	(9.6)	7.1 (6.9)
N of R (or feeds)	4 (2)	6 (3)	12 (6)	N of B in T (P)	(8)	4 (8)
EB	6	8.8	14	EB in T (P)	(33)	43 (46)
NET	159	197	158	NET in T (P)	100 (100)	62 (82)
δT/T [μK/K] (in T)	2.48	3.82	6.30	δT/T [μK/K] in T (P)	2.1 (3.4)	1.6 (2.9)
δT/T [μK/K] (in P)	3.51	5.40	8.91			

Frequency (GHz)	217	353	Frequency (GHz)	545	857
FWHM in T (P)	4.6 (4.6)	4.7 (4.6)	FWHM in T	4.7	4.3
N of B in T (P)	4 (8)	4 (8)	N of B in T	4	4
EB in T (P)	72 (63)	99 (102)	EB in T	169	257
NET in T (P)	91 (132)	277 (404)	NET in T	2000	91000
δT/T [μK/K] in T (P)	3.4 (6.4)	14.1 (26.9)	δT/T [μK/K] in T	106	4243

The first scientific results (http://www.sciops.esa.int/index.php?project=PLANCK&page=Planck_Published_Papers) have been released on January 2011, while few other papers have been released very recently. They describe the instrument performance in flight including thermal behaviour (papers I–IV), the LFI and HFI data analysis pipelines (papers V–VI), the main astrophysical results about Galactic science (papers XIX–XXV), extragalactic sources and far-IR background (papers XIII–XVIII and [3]), and Sunyaev-Zel'dovich effects and cluster properties (papers VIII–XII and [4]), providing to the scientific community the *Planck* Early Release Compact Source Catalog (ERCSC) (paper VII and *The Explanatory Supplement to the Planck Early Release Compact Source Catalogue*).

The presentation of a next set of (some tens of) astrophysical papers is planned by the first half of 2012. Astrophysical papers will be roughly divided into two wide categories: those mainly based only on total intensity data and those requiring well established polarization data. Some of the *Planck* updated astrophysical results will be presented in occasion of the Conference *Astrophysics from radio to sub-millimeter wavelengths: the Planck view and other experiments* to be held in Bologna on 13-17 February 2012. The first publications of the main cosmological implications are expected in early 2013, together with the delivery of a first set of *Planck* maps and cosmological products based on the first 15 months of data. *Planck* will open a new era in our understanding of the universe and of its astrophysical structures (see [5] for descriptions of the *Planck* scientific programme). In this lecture we review the current status of *Planck* data analysis focussing on the production of the first astrophysical results. Moreover, we provide a general overview of the *Planck* fundamental cosmological promises. *Planck* will improve the accuracy of current measures of a wide set of cosmological parameters by a factor from $\sim$ 3 to $\sim$ 10 and will characterize the geometry of the universe
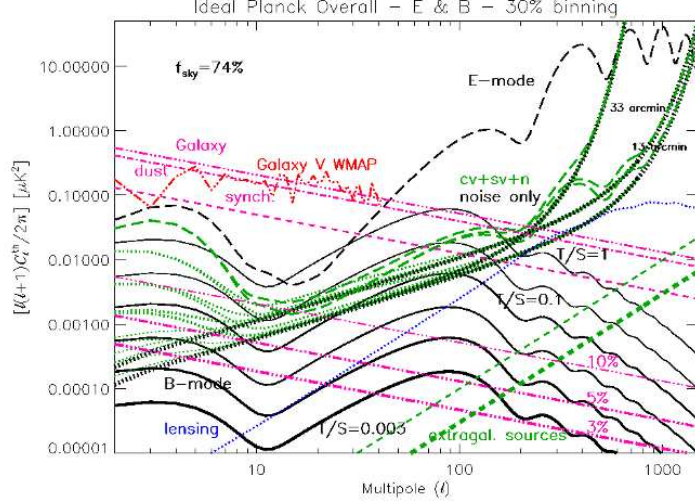
FIG. 3: CMB E polarisation modes (black long dashes) compatible with *WMAP* data and CMB B polarisation modes (black solid lines) for different tensor-to-scalar ratios $T/S = r$ of primordial perturbations) are compared to *Planck* overall sensitivity to the power spectrum for two surveys and whole mission, assuming the noise expectation has been subtracted, and two different FWHM angular resolutions. The plots include cosmic and sampling variance plus instrumental noise (green dots for B modes, green long dashes for E modes, labeled with cv+sv+n; black thick dots, noise only) assuming a multipole binning of 30%. Note that the cosmic and sampling (74% sky coverage excluding the sky regions mostly affected by Galactic emission) variance implies a dependence of the overall sensitivity on r at low multipoles, relevant to the parameter estimation; instrumental noise only determines the capability of detecting the B mode. The B mode induced by lensing (blue dots) is also shown. Galactic synchrotron (purple dashes) and dust (purple dot-dashes) polarised emissions produce the overall Galactic foreground (purple three dot-dashes). *WMAP* 3-yr power-law fits for uncorrelated dust and synchrotron have been used. For comparison, *WMAP* 3-yr results (http://lambda.gsfc.nasa.gov/) derived from the foreground maps using HEALPix tools (http://healpix.jpl.nasa.gov/) [6], which use is acknowledged, are shown: power-law fits provide (generous) upper limits to the power at low multipoles. Residual contamination levels by Galactic foregrounds (purple three dot-dashes) are shown for 10%, 5%, and 3% of the map level, at increasing thickness. We plot also as thick and thin green dashes realistic estimates of the residual contribution of un-subtracted extragalactic sources, $C_\ell^{\mathrm{res,PS}}$ and the corresponding uncertainty, $\delta C_\ell^{\mathrm{res,PS}}$.

with unprecedented accuracy thanks to its excellent mapping and removal of all astrophysical emissions achievable through its so wide frequency coverage. *Planck* will put light on many of the open issues in the connection between the early stages of the universe and the evolution of the cosmic structures, from the characterization of primordial conditions and perturbations to the late phases of cosmological reionization. We discuss also the *Planck* perspectives for some crucial selected topics linking cosmology to fundamental physics (the neutrino masses and effective species number, the primordial helium abundance, the parity property of CMB maps and its connection with CPT symmetry with emphasis to the Cosmic Birefringence, the detection of the stochastic field of gravitational waves through the identification of the so-called B-mode angular power spectrum of the CMB anisotropies – see Fig. 1), showing how *Planck* represents also an extremely powerful fundamental and particle physics laboratory.

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Predictions of the Effective Theory of Inflation in the Standard Model of the Universe and the CMB+LSS data analysis

Inflation is today a part of the Standard Model of the Universe supported by the cosmic microwave background (CMB) and large scale structure (LSS) datasets. Inflation solves the horizon and flatness problems and naturally generates density fluctuations that seed LSS and CMB anisotropies, and tensor perturbations (primordial gravitational waves). Inflation theory is based on a scalar field φ (the inflaton) whose potential is fairly flat leading to a slow-roll evolution.

We focuse here on the following new aspects of inflation. We present the effective theory of inflation à la **Ginsburg-Landau** in which the inflaton potential is a polynomial in the field φ and has the universal form $V(\varphi) = N \ M^4 \ w(\varphi/[\sqrt{N} \ M_{Pl}])$, where $w = \mathcal{O}(1)$, $M \ll M_{Pl}$ is the scale of inflation and $N \sim 60$ is the number of efolds since the cosmologically relevant modes exit the horizon till inflation ends. The slow-roll expansion becomes a systematic $1/N$ expansion and the inflaton couplings become **naturally small** as powers of the ratio $(M/M_{Pl})^2$. The spectral index and the ratio of tensor/scalar fluctuations are $n_s - 1 = \mathcal{O}(1/N)$, $r = \mathcal{O}(1/N)$ while the running index turns to be $dn_s/d\ln k = \mathcal{O}(1/N^2)$ and therefore can be neglected. The **energy scale of inflation** $M \sim 0.7 \times 10^{16}$ GeV turns to be completely determined by the amplitude of the scalar adiabatic fluctuations [1-2].

A complete analytic study plus the Monte Carlo Markov Chains (MCMC) analysis of the available CMB+LSS data (including WMAP5) with fourth degree trinomial potentials showed [1-3]:

- **(a)** the **spontaneous breaking** of the $\varphi \to -\varphi$ symmetry of the inflaton potential.

- **(b)** a **lower bound** for r in new inflation: $r > 0.023$ (95% CL) and $r > 0.046$ (68% CL).

- **(c)** The preferred inflation potential is a **double well**, even function of the field with a moderate quartic coupling yielding as most probable values: $n_s \simeq 0.964$, $r \simeq 0.051$. This value for r is within reach of forthcoming CMB observations.

- **(d)** The present data in the effective theory of inflation clearly **prefer new inflation**.

- **(e)** Study of higher degree inflaton potentials show that terms of degree higher than four do not affect the fit in a significant way. In addition, horizon exit happens for $\varphi/[\sqrt{N} \ M_{Pl}] \sim 0.9$ making higher order terms in the potential w negligible [4].

- **(f)** Within the Ginsburg-Landau potentials in new inflation, n_s and r in the (n_s, r) plane are within the universal banana region fig. 4 and r is in the range $0.021 < r < 0.053$ [4].

We summarize the physical effects of **generic** initial conditions (different from Bunch-Davies) on the scalar and tensor perturbations during slow-roll and introduce the transfer function $D(k)$ which encodes the observable initial conditions effects on the power spectra. These effects are more prominent in the *low* CMB multipoles: a change in the initial conditions during slow roll can account for the observed CMB **quadrupole suppression** [1].

Slow-roll inflation is generically preceded by a short **fast-roll** stage. Bunch-Davies initial conditions are the natural initial conditions for the fast-roll perturbations.

The characteristic time scale of the fast-roll era turns to be $t_1 = (1/m) \ \sqrt{V(0)/[3 \ M^4]} \sim 10^4 \ t_{Planck}$. The **whole** evolution of the fluctuations along the decelerated and inflationary fast-roll and slow-roll eras is computed in ref. [5].

The Bunch-Davies initial conditions (BDic) are generalized for the fast-roll case in which the potential felt by the fluctuations can never be neglected. The fluctuations feel a **singular attractive** potential near the $t = t_*$ singularity (as in the case of a particle in a central singular potential) with **exactly** the **critical** strength $(-1/4)$ allowing the fall to the centre.

The power spectrum gets **dynamically modified** by the effect of the fast-roll eras and the choice of BDic at a finite time, through the transfer function $D(k)$. The power spectrum vanishes at $k = 0$. $D(k)$ presents a first peak for

$k \sim 2/\eta_0$ (η_0 being the conformal initial time), then oscillates with decreasing amplitude and vanishes asymptotically for $k \to \infty$. The transfer function $D(k)$ affects the **low** CMB multipoles C_ℓ: the change $\Delta C_\ell/C_\ell$ for $1 \le \ell \le 5$ is computed in [5] as a function of the starting instant of the fluctuations t_0. CMB quadrupole observations indicate large **suppressions** which are well reproduced for the range $t_0 - t_* \gtrsim 0.05/m \simeq 10100\, t_{Planck}$.

A MCMC analysis of the WMAP+SDSS data **including fast-roll** shows that the quadrupole mode exits the horizon about 0.2 efold before fast-roll ends and its amplitude gets suppressed. In addition, fast-roll fixes the **initial inflation redshift** to be $z_{init} = 0.9 \times 10^{56}$ and the **total number** of efolds of inflation to be $N_{tot} \simeq 64$ [1,3]. Fast-roll fits the TT, the TE and the EE modes well reproducing the quadrupole supression.

A thorough study of the **quantum loop corrections** reveals that they are very small and controlled by powers of $(H/M_{Pl})^2 \sim 10^{-9}$, **a conclusion that validates the reliability of the effective theory of inflation [1].**

This work [1-4] shows how powerful is the Ginsburg-Landau effective theory of inflation in predicting observables that are being or will soon be contrasted to observations.

The Planck satellite is right now measuring with unprecedented accuracy the primary CMB anisotropies. The Standard Model of the Universe (including inflation) provides the context to analyze the CMB and other data. The Planck performance for r related to the primordial B mode polarization, will depend on the quality of the data analysis.

The Ginsburg Landau approach to inflation allows to take high benefit of the CMB data. We evaluate the Planck precision to the recovery of cosmological parameters within a reasonable toy model for residuals of systematic effects of instrumental and astrophysical origin based on publicly available information. We use and test two relevant models: the ΛCDMr model, i. e. the standard ΛCDM model augmented by r, and the ΛCDMrT model, where the scalar spectral index, n_s, and r are related through the theoretical 'banana-shaped' curve $r = r(n_s)$ coming from the double-well inflaton potential (upper boundary of the banana region fig. 4. In the latter case, $r = r(n_s)$ is imposed as a hard constraint in the MCMC data analysis. We take into account the white noise sensitivity of Planck in the 70, 100 and 143 GHz channels as well as the residuals from systematics errors and foregrounds. Foreground residuals turn to affect only the cosmological parameters sensitive to the B modes [6].

In the Ginsburg-Landau inflation approach, better measurements on n_s, as well as on TE and EE modes will improve the prediction on r even if a detection of B modes is still lacking [6].

Forecasted B mode detection probability by the most sensitive HFI-143 channel: At the level of foreground residual equal to 30% of our toy model, only a 68% CL detectiof r is very likely. For a 95% CL detection the level of foreground residual should be reduced to 10% or lower of the adopted toy model. The possibility to detect r is borderline [6].
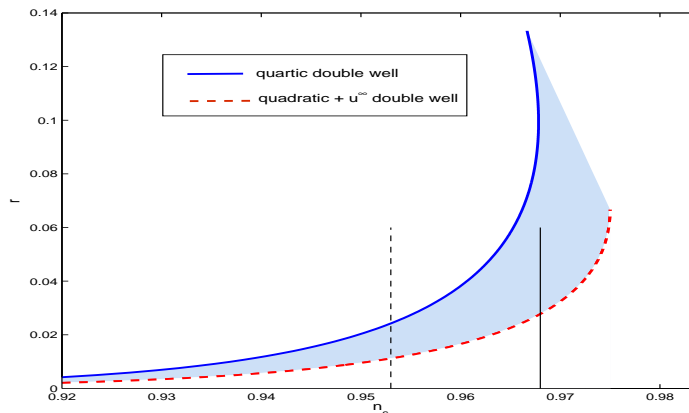
FIG. 4: The universal banana region $\mathcal{B}$ in the (n_s, r)-plane setting $N = 60$. The upper border of the region $\mathcal{B}$ corresponds to the fourth order double–well potential (new inflation). The lower border is described by the potential $V(\varphi) = \frac{1}{2}m^2 \left(\frac{m^2}{\lambda} - \varphi^2 \right)$ for $\varphi^2 < m^2/\lambda$ and $V(\varphi) = \infty$ for $\varphi^2 > m^2/\lambda$ [4]. We display in the vertical full line the observed value $n_s = 0.968 \pm 0.015$ using the WMAP+BAO+SN data set. The broken vertical lines delimit the $\pm 1\,\sigma$ region.

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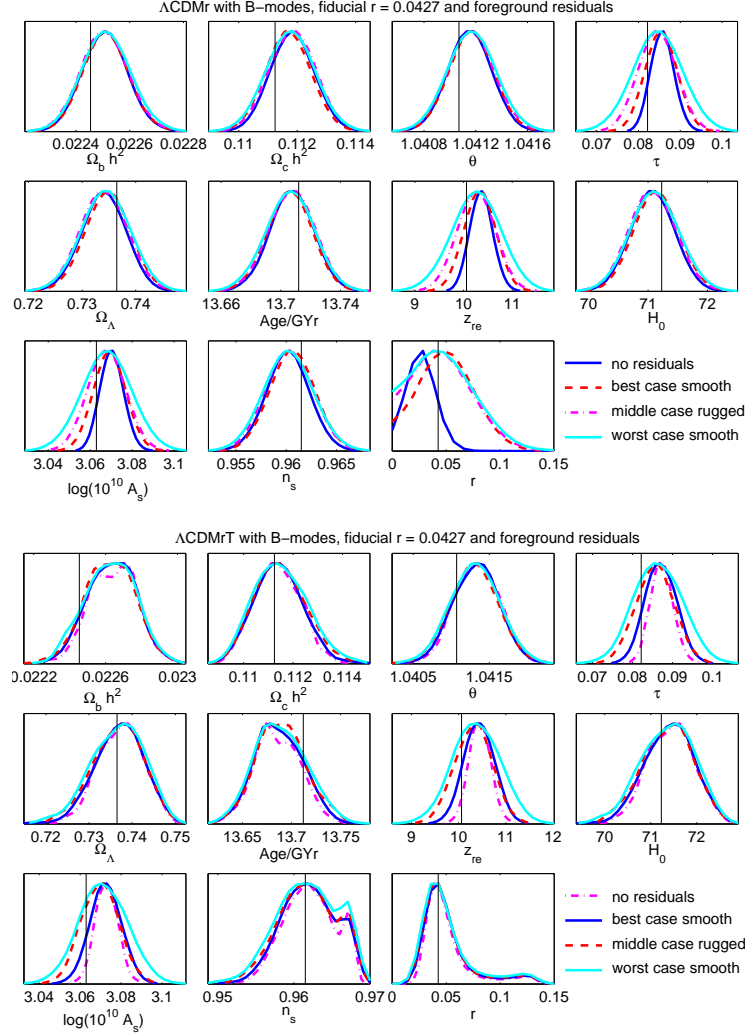
FIG. 5: Forecasts for Planck [6]. Upper panel: Cumulative 3−channel marginalized likelihood distributions, including B modes and foreground residuals, of the cosmological parameters for the ΛCDMr model. The fiducial ratio is $r = 0.0427$. Lower panel: Cumulative marginalized likelihoods from the three channels for the cosmological parameters for the ΛCDMrT model including B modes and fiducial ratio $r = 0.0427$ and the foreground residuals. We plot the distributions in four cases: (a) without residuals, (b) best case smooth: with 30% of the toy model residuals in the TE and E modes. (c) worst case smooth: with the toy model residuals in the TE and E modes. (d) with 65% of the toy model residuals in the TE and E modes and $88\mu K^2$ in the T modes rugged by Gaussian fluctuations of 30% relative strength.

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keV scale dark matter from theory and observations and galaxy properties from linear primordial fluctuations

In the context of the standard Cosmological model the nature of dark matter (DM) is unknown. Only the DM gravitational effects are noticed and they are necessary to explain the present structure of the Universe. DM particle candidates are not present in the standard model (SM) of particle physics. Particle model independent theoretical analysis combined with astrophysical data from galaxy observations points towards a DM particle mass in the **keV scale** (keV = 1/511 electron mass) [1-4]. Many extensions of the SM can be envisaged to include a DM particle with mass in the keV scale and weakly enough coupled to the Standard Model particles to fulfill all particle physics experimental constraints.

DM particles can decouple being ultrarelativistic (UR) at $T_d \gg m$ or non-relativistic $T_d \ll m$. They may decouple at or out of local thermal equilibrium (LTE). The DM distribution function: $F_d[p_c]$ freezes out at decoupling becoming a function of the comoving momentum $p_c =$. $P_f(t) = p_c/a(t) =$ is the physical momentum. Basic physical quantities can be expressed in terms of the distribution function as the velocity fluctuations, $\langle \vec{V}^2(t) \rangle = \langle \vec{P}_f^2(t) \rangle / m^2$ and the DM energy density $\rho_{DM}(t)$ where $y = P_f(t)/T_d(t) = p_c/T_d$ is the integration variable and g is the number of internal degrees of freedom of the DM particle; typically $1 \le g \le 4$.

Two basic quantities characterize DM: its particle mass m and the temperature T_d at which DM decouples. T_d is related by entropy conservation to the number of ultrarelativistic degrees of freedom g_d at decoupling by $T_d = (2/g_d)^{\frac{1}{3}} T_{cmb}$, $T_{cmb} = 0.2348\ 10^{-3}$ eV. One therefore needs **two** constraints to determine the values of m and T_d (or g_d).

One constraint is to reproduce the known cosmological DM density today. $\rho_{DM}(\text{today}) = 1.107 \text{ keV/cm}^3$.

Two independent further constraints are considered in refs. [1-4]. First, the phase-space density $Q = \rho/\sigma^3$ [1-2] and second the surface acceleration of gravity (surface density) in DM dominated galaxies [3-4]. We therefore provide **two** quantitative ways to derive the value m and g_d in refs. [1-4].

The phase-space density Q is invariant under the cosmological expansion and can **only decrease** under self-gravity interactions (gravitational clustering). The value of Q today follows observing dwarf spheroidal satellite galaxies of the Milky Way (dSphs): $Q_{today} = (0.18 \text{ keV})^4$ (Gilmore et al. 07 and 08). We compute explicitly Q_{prim} (in the primordial universe) and it turns to be proportional to m^4 [1-4].

During structure formation Q **decreases** by a factor that we call Z. Namely, $Q_{today} = Q_{prim}/Z$. The value of Z is galaxy-dependent. The spherical model gives $Z \simeq 41000$ and N-body simulations indicate: $10000 > Z > 1$ (see [1]). Combining the value of Q_{today} and $\rho_{DM}(\text{today})$ with the theoretical analysis yields that m must be in the keV scale and T_d can be larger than 100 GeV. More explicitly, we get general formulas for m and g_d [1]:

$$m = \frac{2^{\frac{1}{4}} \sqrt{\pi}}{3^{\frac{3}{8}} g^{\frac{1}{4}}} Q_{prim}^{\frac{1}{4}} I_4^{\frac{3}{8}} I_2^{-\frac{5}{8}}, \quad g_d = \frac{2^{\frac{1}{4}} g^{\frac{3}{4}}}{3^{\frac{3}{8}} \pi^{\frac{3}{2}} \Omega_{DM}} \frac{T_\gamma^3}{\rho_c} Q_{prim}^{\frac{1}{4}} [I_2 I_4]^{\frac{3}{8}}$$

where $I_{2n} = \int_0^\infty y^{2n} F_d(y)\ dy$, $n = 1, 2$ and $Q_{prim}^{\frac{1}{4}} = Z^{\frac{1}{4}}$ 0.18 keV using the dSphs data, $T_\gamma = 0.2348 \text{ meV}$, $\Omega_{DM} = 0.228$ and $\rho_c = (2.518 \text{ meV})^4$. These formulas yield for relics decoupling UR at LTE:

$$m = \left(\frac{Z}{g}\right)^{\frac{1}{4}} \text{ keV} \begin{cases} 0.568 \\ 0.484 \end{cases}, g_d = g^{\frac{3}{4}} Z^{\frac{1}{4}} \begin{cases} 155 & \text{Fermions} \\ 180 & \text{Bosons} \end{cases}.$$

Since $g = 1-4$, we see that $g_d \gtrsim 100 \Rightarrow T_d \gtrsim 100$ GeV. Moreover, $1 < Z^{\frac{1}{4}} < 10$ for $1 < Z < 10000$. For example for DM Majorana fermions ($g = 2$) $m \simeq 0.85$ keV.

We get results for m and g_d on the same scales for DM particles decoupling UR out of thermal equilibrium [1]. For a specific model of sterile neutrinos where decoupling is out of thermal equilibrium:

$$0.56 \text{ keV} \lesssim m_\nu\ Z^{-\frac{1}{4}} \lesssim 1.0 \text{ keV} \quad, \quad 15 \lesssim g_d\ Z^{-\frac{1}{4}} \lesssim 84$$

For relics decoupling non-relativistic we obtain similar results for the DM particle mass: keV $\lesssim m \lesssim$ MeV [1].

Notice that the dark matter particle mass m and decoupling temperature T_d are **mildly** affected by the uncertainty in the factor Z through a power factor $1/4$ of this uncertainty, namely, by a factor $10^{\frac{1}{4}} \simeq 1.8$

The comoving free-streaming) wavelength, and the Jeans' mass are obtained in the range

$$\frac{0.76}{\sqrt{1+z}} \text{ kpc} < \lambda_{fs}(z) < \frac{16.3}{\sqrt{1+z}} \text{ kpc} \ , \ 0.45 \ 10^3 \ M_\odot < \frac{M_J(z)}{(1+z)^{+\frac{3}{2}}} < 0.45 \ 10^7 \ M_\odot \ .$$

These values at $z = 0$ are consistent with the N-body simulations and are of the order of the small dark matter structures observed today . By the beginning of the matter dominated era $z \sim 3200$, the masses are of the order of galactic masses $\sim 10^{12} \ M_\odot$ and the comoving free-streaming wavelength scale turns to be of the order of the galaxy sizes today ~ 100 kpc.

Lower and upper bounds for the dark matter annihilation cross-section σ_0 are derived: $\sigma_0 > (0.239 - 0.956) \ 10^{-9} \ \text{GeV}^{-2}$ and $\sigma_0 < 3200 \ m \ \text{GeV}^{-3}$. There is at least five orders of magnitude between them, the dark matter non-gravitational self-interaction is therefore negligible (consistent with structure formation and observations, as well as by comparing X-ray, optical and lensing observations of the merging of galaxy clusters with N-body simulations).

Typical 'wimps' (weakly interacting massive particles) with mass $m = 100$ GeV and $T_d = 5$ GeV would require a huge $Z \sim 10^{23}$, well above the upper bounds obtained and cannot reproduce the observed galaxy properties. They produce an extremely short free-streaming or Jeans length λ_{fs} today $\lambda_{fs}(0) \sim 3.51 \ 10^{-4}$ pc = 72.4 AU that would correspond to unobserved structures much smaller than the galaxy structure. Wimps result are strongly disfavoured.

Galaxies are described by a variety of physical quantities:

(a) **Non-universal** quantities: mass, size, luminosity, fraction of DM, DM core radius r_0, central DM density ρ_0.
(b) **Universal** quantities: surface density $\mu_0 \equiv r_0 \ \rho_0$ and DM density profiles. M_{BH}/M_{halo} (or halo binding energy). The galaxy variables are related by **universal** empirical relations. Only one variable remains free. That is, the galaxies are a one parameter family of objects. The existence of such universal quantities may be explained by the presence of attractors in the dynamical evolution. The quantities linked to the attractor always reach the same value for a large variety of initial conditions. This is analogous to the universal quantities linked to fixed points in critical phenomena of phase transitions.The universal DM density profile in Galaxies has the scaling property:

$$\rho(r) = \rho_0 \ F\left(\frac{r}{r_0}\right) \quad , \quad F(0) = 1 \quad , \quad x \equiv \frac{r}{r_0} \ ,$$

where r_0 is the DM core radius. As empirical form of cored profiles one can take Burkert's form for $F(x)$. Cored profiles **do reproduce** the astronomical observations.

The surface density for dark matter (DM) halos and for luminous matter galaxies is defined as: $\mu_{0D} \equiv r_0 \ \rho_0$, $r_0 =$ halo core radius, $\rho_0 =$ central density for DM galaxies. For luminous galaxies $\rho_0 = \rho(r_0)$ (Donato et al. 09, Gentile et al. 09). Observations show an Universal value for μ_{0D}: independent of the galaxy luminosity for a large number of galactic systems (spirals, dwarf irregular and spheroidals, ellipticals) spanning over 14 magnitudes in luminosity and of different Hubble types. Observed values:

$$\mu_{0D} \simeq 120 \ \frac{M_\odot}{\text{pc}^2} = 5500 \ (\text{MeV})^3 = (17.6 \ \text{Mev})^3 \quad , \quad 5\text{kpc} < r_0 < 100\text{kpc} \ .$$

Similar values $\mu_{0D} \simeq 80 \ \frac{M_\odot}{\text{pc}^2}$ are observed in interstellar molecular clouds of size r_0 of different type and composition over scales $0.001 \, \text{pc} < r_0 < 100$ pc (Larson laws, 1981). Notice that the surface gravity acceleration is given by μ_{0D} times Newton's constant.

We combine in refs.[3-4] the theoretical evolution of density fluctuations computed from first principles since decoupling till today to the observed properties of galaxies as the surface density and core radius. We obtain that (i) the dark matter particle mass must be in the keV scale both for in and out of thermal equilibrium decoupling (ii) the density profiles are cored for keV scale DM particles and cusped for GeV scale DM particles (wimps).

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Cosmology from ACT: the small-scale CMB

Introduction: The Cosmic Microwave Background has been measured over the whole sky by three generations of satellites at increasingly high resolution: COBE, WMAP, and currently Planck. The Atacama Cosmology Telescope (ACT) measures a small fraction of the sky, but at even higher resolution and sensitivity [1]. In doing so it measures not only the primordial light from the time of recombination at $z \sim 1100$, but also secondary distortions to the light from intervening cosmic structures, and additional microwave emission from individual galaxies.

ACT is located at an elevation of 5190m in the Atacama desert in Chile, one of the driest locations on the planet. It has a 6m primary mirror and over 3000 detectors at three frequencies in the range 148-270 GHz. It has observed the microwave sky for four seasons from 2007-2010, covering about 800 square degrees at arcminute resolution, in a Southern region at -55° declination, and a celestial Equatorial region overlapping with the SDSS Stripe 82. Maps of the microwave sky are generated using a maximum likelihood map-maker, solving for the sky signal simultaneously with the atmospheric signal, for the detector arrays at each frequency.

The CMB spectrum from ACT: The power spectrum was estimated from the 2008 Southern data at 148 and 220 GHz using the flat-sky approximation, and is reported in [2] in the angular range $500 < \ell < 10000$. At large scales the signal is dominated by the primordial CMB, and the Silk damping tail is clearly seen. At smaller scales the extragalactic point source power dominates, with a larger contribution at 220 GHz due to thermal dust emission from star-forming galaxies. As reported in [3], the total spectrum is well fit by the sum of a lensed CMB component, a Sunyaev-Zel'dovich (SZ) contribution, and both radio and infrared emission from individual galaxies. Focusing on the CMB-dominated region, seven acoustic peaks can now be seen, as shown in Figure 6 from [3]. The spectrum is consistent with the ΛCDM model estimated from WMAP data [4]. The broader range of angular scales now make it possible to rule out certain cosmological models that were previously degenerate with ΛCDM at larger scales, but that have different degrees of Silk damping and peak positions at smaller scales.

Inflation and early universe physics: We have estimated cosmological parameters from ACT combined with the WMAP 7-year data [4], and late-time Baryon Acoustic Oscillation and Hubble constant data. This leads to improved limits on inflationary parameters including the primordial spectral index, running of the spectral index with scale, and tensor-to-scalar ratio, all reported in [3]. A measure of the primordial spectrum as a function of scale is reported in [5], finding no significant deviations from power law fluctuations. We also better constrain the effective number of neutrino species, detect primordial helium at high significance, and constrain the possible string tension of an additional cosmic string component. The final ACT spectrum, together with the recently published spectrum from the South Pole Telescope [6], promises to further test early universe physics.

Late-time effects: The primary CMB provides an excellent probe of inflationary and early universe parameters, and allows a measure of the relative densities of components in the universe, if a flat geometry is assumed. However,
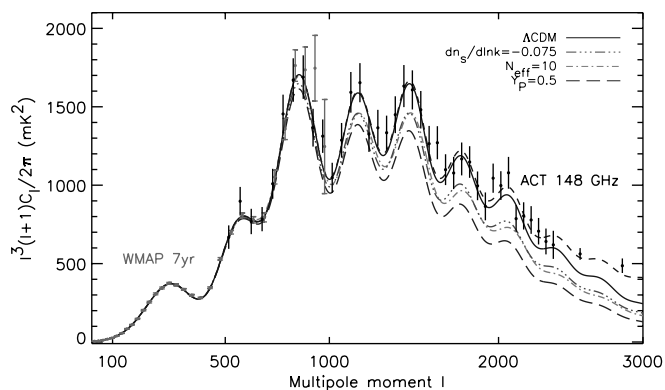

FIG. 6: *Figure from Dunkley et al. 2011 [3]:* Four cosmological models that are degenerate at large scales can be distinguished at smaller scales using ACT, constraining the number of neutrino species, helium fraction, and running of the spectral index.
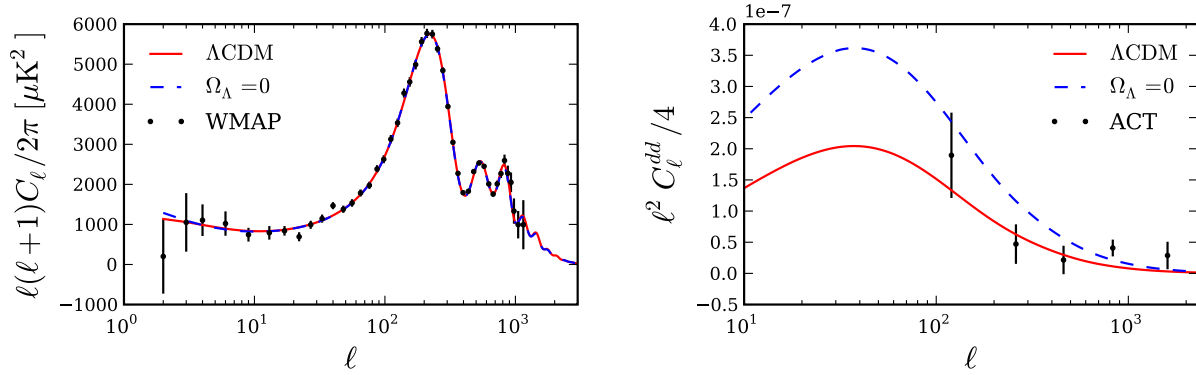
FIG. 7: *Figure from Sherwin et al. 2011 [8]:* Two models that are degenerate in CMB temperature power (left) can be distinguished using CMB lensing (right): the curved model with no Dark Energy gives more lensing than the ΛCDM model.

the well-known geometric degeneracy prevents the expansion rate and geometry from both being determined from the CMB. To measure the geometry and behaviour of dark energy as a function of cosmic time, lower-redshift probes are necessary. However, the small-scale CMB can now also be used to probe late-time physics, due to secondary effects.

Lensing: CMB photons are gravitationally deflected by large-scale structure potentials, with deflection angles typically a few arcminutes. A measurement of the deflection field can provide a measurement of the matter fluctuations and the geometry of the universe. Lensing directly affects the temperature power spectrum by smoothing the acoustic peaks and increasing small-scale power, and is observed at almost 3σ in the ACT power spectrum [2]. This detection is improved by reconstructing the lensing field directly, using the property that lensing couples modes of different scales, generating a non-zero 4-point function in excess of that expected for a Gaussian field. Measuring the lensing 4-point function has led to a 4σ detection of the lensing power spectrum in the Equatorial ACT data, reported in [7] as the first direct detection of CMB lensing. The deflection power is consistent with the ΛCDM model, and helps constrain cosmological models. A universe with no dark energy, and positive spatial curvature, fits the CMB temperature spectrum almost as well as a flat ΛCDM model, as shown in Figure 7. However, this model has enhanced lensing deflection power, and is disfavored at more than 3σ when the lensing data is included [8]. The CMB alone can now provide evidence for a dark energy component in the universe.

Sunyaev-Zel'dovich: The CMB is inverse Compton scattered by hot electrons in galaxy clusters, shifting the black-body spectrum such that clusters can be identified. Their number as a function of mass and redshift is sensitive to the evolution of structure formation, and can be used to probe properties of dark energy and structure growth. In the Southern 2008 ACT data, 23 clusters were detected and optically confirmed at high significance [9,10], and a further sample have been detected in the Equatorial data. Constraints on cosmological parameters from cluster counts are consistent with the ΛCDM model [11], although constraints are limited by uncertainties in the cluster masses. The mass is expected to scale with the SZ signal, and such scaling relations have been observed in the ACT data [12]; further multi-wavelength observations are expected to better determine masses and improve constraints.

Conclusion: By considering the primordial CMB power spectrum, lensing deflection estimates, and cluster number counts, all measured with ACT, the ΛCDM cosmological model is found to be consistent over a wide range of scales and redshifts. The ACT receiver was removed from the telescope early 2011, and the upgraded receiver, ACTPol, is due to begin observations in 2012. With improved sensitivity and polarization capabilities, it will measure the primordial power spectrum in polarization, and allow a significantly improved measurement of the lensing signal.

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Observational Imprints of Dark Matter on Small Astrophysical Scales

If elementary particles make up (most of) Dark Matter, the properties of the (probably several) different particles will leave an imprint on the power spectrum at small scales. These imprints will in turn affect the smallest gravitational potential wells, and will in turn affect the observable properties of the galaxies which today occupy the smallest potential wells. On similar scales, astrophysical effects - such as the minimum potential in which metal-free primordial gas can readily cool to form stars- are known to be important. Distinguishing between astrophysics and particle physics in the histories of small systems today is thus both challenging and important. The smallest galaxies, those with masses in the range where particle properties will be observable if they exist, are the dSph galaxies. These low-luminosity systems are studied in detail only in the Local Group, with extant facilities.

Substantial efforts are being made to quantify both the statistical (number counts, correlations, spatial distributions..) and the internal properties (star formation histories, dark matter density profiles, ...) of these low-mass systems.

Recent discovery surveys have accentuated the **Satellite Problem**. Although some 25 dSph are now known assciated with each of the Milky way and M31, their numbers remain orders of magnitude too low compared to simple LCDM predictions. Further, the spatial distributions of these satellites are concentrated in sheets/groups, more so than is anticipated. Early hints that the dSph have a radically different **Half-Light Size Distribuion** than do baryonic (star cluster) systems, and are - when sufficiently far from a deep tidal field – all larger than about 100-pc [1], are still apparent. Does this reflect an underlying scale in the dark matter? Why are such low-luminosity galaxies so large?

A key requirement is to quantify the role of **Baryonic Feedback** on galaxy formation. Dominant feedback is required in LCDM to solve the Satellite Problem, and to reproduce something like the observed galaxy luminosity function. Feedback is not a free parameter, to be sub-grid fixed. It is a consequence of the star formation rate, which is determinable from the **chemical abundance distribution function of the earliest stars**. Substantial progress is being made in quantifying the early histories of the local dSph. In all cases, very low star formation rates are required by observation. This implies **very low baryonic feedback.** It also implies that the field stars in the Milky Way **were not formed in now tidally destroyed** dSph. Appropriate high-resolution simulation efforts [2.3] conclude that **baryon feedback does not affect DM structure** and that CDM still cannot produce realistic galaxies with realistic feedback and star formation recipes.

Direct kinematic probing of dSph density profiles is making significant progress. Substantially improved techniques have been developed and implemented to derive very precise kinematics for faint stars in dSph [4]. Sophisticated distribution-function methodes for deriving potentials from projected kinematics continue to be developed, albeit slowly. Serious effort is being invested to find ways to test the effect on the host galaxy of the tens of thousands of star-less CDM halos predicted. Most interestingly, several authors have recently confirmed that the total mass enclosed within a half-light radius is a robust parameter. Clever new work [5] is using the existence of multiple populations inside a single dSph galaxy to determine the mass enclosed with the half-light radius of each population, thus providing several integrated mass determinations inside a single profile.

This new kinematic and chemical abundance work has considerable potential to provide direct determinations of what are apparently primordial DM-dominated density profiles.

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Large-scale peculiar flows of clusters of galaxies: measurements and implications

Peculiar velocities of cosmological objects provide an important test of the physics and initial conditions in the earliest moments of the Universe's evolution. In standard cosmological paradigm, large-scale peculiar velocities arise from gravitational instability due to mass inhomogeneities seeded during inflationary expansion. On sufficiently large scales, $\gtrsim 100$ Mpc, this leads to a robust prediction of the amplitude and coherence length of these velocities independently of cosmological parameters or evolution of the Universe. A variety of methods have been employed over the years to measure peculiar velocities starting with several galaxy distance indicators. For clusters of galaxies, their peculiar velocities can be measured from the kinematic component of the Sunyaev-Zeldovich (KSZ) effect produced by the Compton scattering of the cosmic microwave background (CMB) photons off the hot intracluster gas.

Here we present the results of the measurements of the large-scale peculiar velocities we have conducted over the past several years. The measurements utilize the method proposed by Kashlinsky & Atrio-Barandela [1] which uses the cumulative KSZ effect from an all-sky catalog of X-ray clusters. The method identified a statistic (the dipole of the CMB temperature field evaluated over cluster catalog pixels) which can isolate a signal remaining from the KSZ effect produced by coherently moving clusters. The X-ray cluster catalog was assembled for this purpose from the ROSAT all-sky survey data and, as of now, contains about $\sim 1,500$ clusters with spectroscopically measured redshifts. It is then applied to all-sky CMB maps from the WMAP satellite from the 3-, 5-, and 7-yr total integrations. The results have been been presented in multiple refereed publications [2-7] and a comprehensive summary is now being prepared for Physics Reports [8].

Our results first established that the cluster hot gas distribution is, on average, well described by the NFW density profiles [2]. Because the hydrostatic equilibrium temperature of the NFW-like distributed gas decreases towards outer radii, the thermal SZ (TSZ) component from such clusters decreases with increasing aperture size. This empirically established property was then used by us in [3,4] for 3-yr WMAP data to identify a statistically significant dipole remaining at apertures containing zero CMB monopole, $\langle \delta T \rangle$. The signal was present, at high statistical significance, exclusively at the cluster pixels associated with the apertures containing hot gas (within which $\langle \delta T \rangle$ was still systematically negative) and its amplitude remained constant (within the statistical uncertainties) out to the largest depths probed. After assembling and using a much larger (X-ray luminosity limited) cluster catalog with 5-yr WMAP data, coupled with a revised statistical treatment accounting for correlations between primary CMB remaining in different WMAP channels, we have confirmed the signal and demonstrated that the amplitude of the dipole remaining at zero monopole aperture increases systematically with the cluster L_X-bin. This confirms that the signal must originate from the SZ component and is inconsistent with it arising from some putative systematics originating in primary CMB or instruments.

In [6] we have developed an analytical formalism to understand the errors in our measurement - which has been further verified with numerical/empirical data analysis - and have shown that our filtering scheme removes primary CMB down to the fundamental limit imposed by the cosmic variance; any alternative filtering scheme must satisfy the formalism developed there. Because the dipole is measured at zero monopole and its amplitude correlates well with the cluster L_X, we believe that KSZ is the only viable explanation of the detected signal and its properties; no other explanation has been proposed in the literature as of now. The larger cluster catalog has enabled binning by the cluster L_X resulting in a more accurate measurement extending to significantly larger scales. The measured dipole implies a flow of about 600-1,000 km/sec remaining coherent out to at least ~ 750 Mpc.

In [7] we have shown that the signal can be readily confirmed with the existing *public* cluster data in 5- and 7-yr WMAP data; to facilitate verification and enable better testing of the result we have made the data publicly available from `http://www.kashlinsky.info/bulkflows/data_public`.

We further address consistency of these large scale measurements with peculiar velocities on smaller scales derived independently by different techniques. The results cast doubt that the gravitational instability from the observed mass distribution is the sole - or even dominant - cause of the detected motions. Instead it appears that the flow extends across the observable Universe and may be indicative of either the globally different world structure (such as the primeval preinflationary structure of space-time and its landscape), or require modifications of known physics

(e.g. arising from higher-dimensional structure of gravity). We review these possibilities in light of the measurements discussed here.

In order to improve the results, still better eliminate any possible systematics and to measure the 'dark flow' - and its properties - with higher accuracy and to still large scales, we have designed an experiment dubbed *SCOUT* (**S**unyaev-Zeldovich **C**luster **O**bservations as probes of the **U**niverse's **T**ilt) which we are currently conducting. The *SCOUT* experiment will catalog up to $\sim 2,000$ clusters of galaxies extending to $z \sim 0.7$ and double the depth of the measured flow and its accuracy, while improving the current calibration uncertainties, upon application to forthcoming CMB data releases.

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Testing the Standard Model with the Primordial Inflation Explorer

Inflation has a central place in modern cosmology. The many *e*-foldings of the scale size during inflation force the geometry of space-time to asymptotic flatness while dilating quantum fluctuations in the inflaton potential to the macroscopic scales responsible for seeding large-scale structure in the universe. Inflation provides a simple, elegant solution to multiple problems in cosmology, but it relies on extrapolation of physics to energies greatly exceeding direct experimentation in particle accelerators.

Linear polarization of the cosmic microwave background (CMB) provides a direct test of inflationary physics. Gravity waves generated during inflation later interact with the CMB to impart a characteristic curl pattern (B-mode) in the linear polarization. Detecting the innflationary signature in polarization will be difficult. As recognized in multiple reports [1–3], there are three fundamental challenges: sensitivity, foreground emission from within the Galaxy, and rigorous control of systematic errors from instrumental effects. Satisfying the simultaneous requirements of sensitivity, foreground discrimination, and immunity to systematic errors presents a technological challenge.

The Primordial Inflation Explorer (PIXIE) is an Explorer-class mission to detect and characterize the polarization signal from an inflationary epoch in the early Universe. Figure 1 shows the instrument concept. PIXIE combines multi-moded optics with a Fourier Transform Spectrometer (FTS) to provide breakthrough sensitivity for CMB polarimetry using only four semiconductor detectors. The design addresses each of the principal challenges for CMB polarimetry. A multi-moded "light bucket" provides nK sensitivity using only four detectors. A polarizing Fourier Transform Spectrometer (FTS) synthesizes 400 channels across 2.5 decades in frequency to provide unparalleled separation of CMB from Galactic foregrounds. PIXIE's highly symmetric design enables operation as a nulling polarimeter to provide the necessary control of instrumental effects.
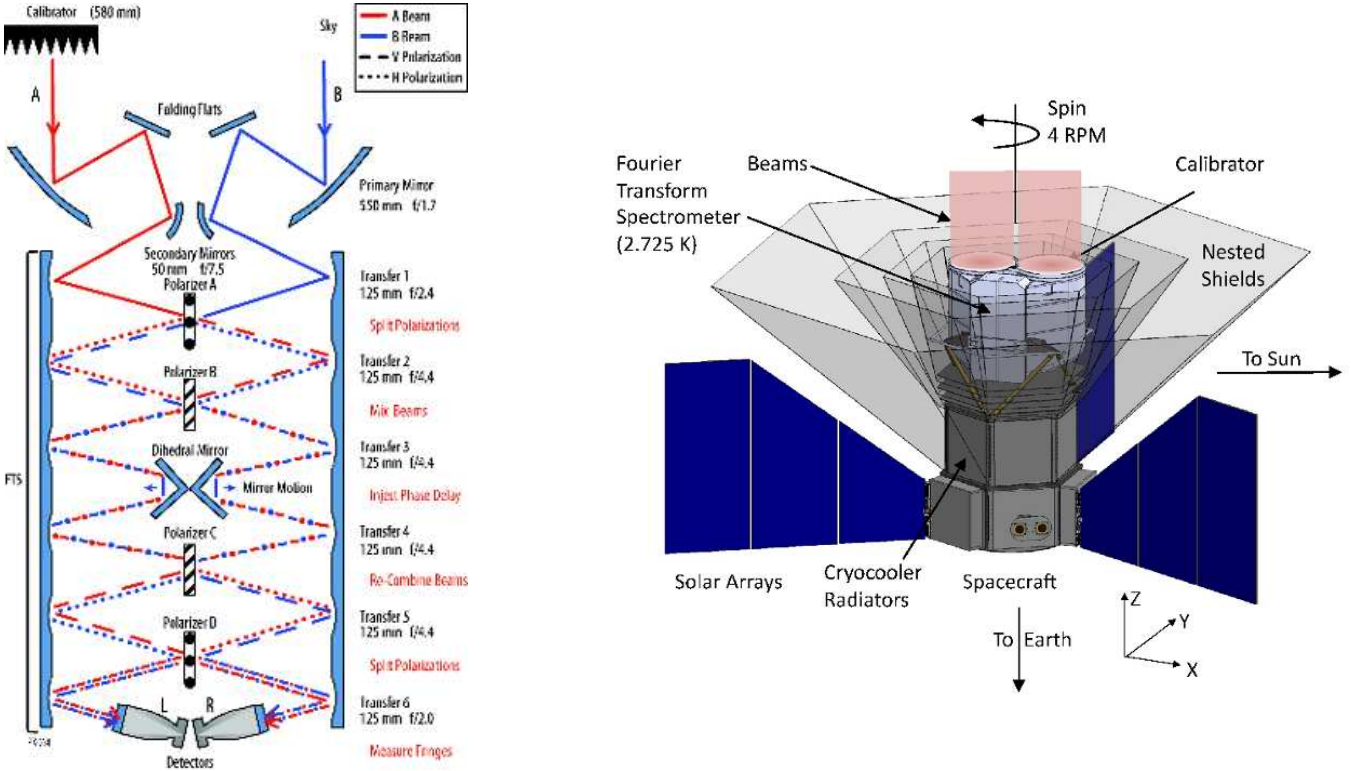
FIG. 8: (Left) PIXIE optical signal path. As the dihedral mirrors move, the detectors measure a fringe pattern proportional to the Fourier transform of the difference spectrum between orthogonal polarization states from the two input beams (Stokes Q in instrument coordinates). A full-aperture blackbody calibrator can move to block either input beam, or be stowed to allow both beams to view the same patch of sky. (Right) PIXIE observatory with calibrator stowed. PIXIE spins at 4 RPM and will observe from a 660 km polar sun-synchronous orbit.

A dihedral mirror within the FTS translates ±2.5mm to provide ±10 mm optical phase delay between the two input beams. The power at the detectors as a function of the dihedral position z may be written

$$
\begin{aligned}
P_{Lx} &= \frac{1}{2} \int (E_{Ax}^2 + E_{By}^2) + (E_{Ax}^2 - E_{By}^2)\cos(4z\omega/c)d\omega \\
P_{Ly} &= \frac{1}{2} \int (E_{Ay}^2 + E_{Bx}^2) + (E_{Ay}^2 - E_{Bx}^2)\cos(4z\omega/c)d\omega \\
P_{Rx} &= \frac{1}{2} \int (E_{Ay}^2 + E_{Bx}^2) + (E_{Bx}^2 - E_{Ay}^2)\cos(4z\omega/c)d\omega \\
P_{Ry} &= \frac{1}{2} \int (E_{Ax}^2 + E_{By}^2) + (E_{By}^2 - E_{Ax}^2)\cos(4z\omega/c)d\omega \; ,
\end{aligned}
\tag{VI.1}
$$

where ω is the angular frequency of incident radiation, x and y are orthogonal polarizations on the sky, L and R refer to the detectors in the left and right concentrators, and A and B refer to the two input beams. PIXIE operates as a nulling polarimeter: when both beams view the sky, the instrument nulls all unpolarized emission so that the FTS fringe pattern responds only to the sky polarization. The resulting null operation greatly reduces sensitivity to systematic errors from unpolarized sources. Normally the instrument collects light from both co-aligned telescopes. A full-aperture blackbody calibrator can move to block either beam, replacing the sky signal in that beam with an absolute reference source near 2.7 K, or be stowed to allow both beams to view the same sky patch. When the calibrator blocks either beam, the fringe pattern encodes information on both the temperature distribution on the sky (Stokes I) as well as the linear polarization. Interleaving observations with and without the calibrator allows straightforward transfer of the absolute calibration scale to linear polarization, while providing a valuable cross-check of the polarization solutions obtained in each mode.

PIXIE will map the full sky in both absolute intensity and linear polarization (Stokes I, Q, and U parameters) with angular resolution 2.° in each of 400 frequency channels 15 GHz wide from 30 GHz to 6 THz. Typical sensitivities within each $1° \times 1°$ pixel are

$$
\delta I_\nu^I = 4 \times 10^{-24} \text{ W m}^{-2} \text{ s}^{-1} \text{ sr}^{-1}
$$

for Stokes I and

$$
\delta I_\nu^{QU} = 6 \times 10^{-25} \text{ W m}^{-2} \text{ s}^{-1} \text{ sr}^{-1}
$$
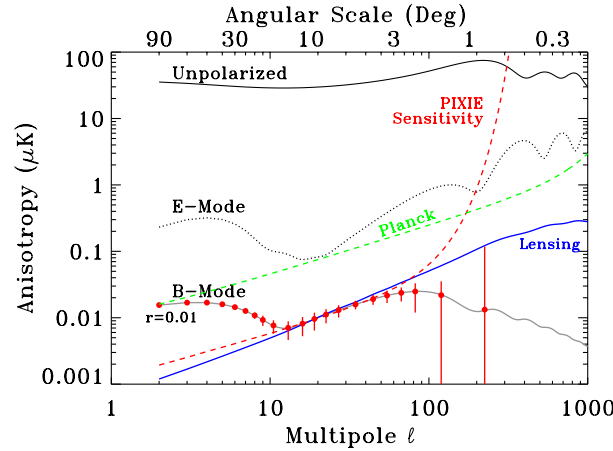
FIG. 9:   Angular power spectra for unpolarized, E-mode, and B-mode polarization in the cosmic microwave background. The dashed red line shows the PIXIE sensitivity to B-mode polarization at each multipole moment $\ell \sim 180 \deg /\theta$. The sensitivity estimate assumes a 4-year mission and includes the effects of foreground subtraction within the cleanest 75% of the sky combining PIXIE data at frequencies $\nu < 600$ GHz. Red points and error bars show the response within broader ℓ bins to a B-mode power spectrum with amplitude $r = 0.01$. PIXIE will reach the confusion noise (blue curve) from the gravitational lensing of the E-mode signal by cosmic shear along each line of sight, and has the sensitivity and angular response to measure even the minimum predicted B-mode power spectrum at high statistical confidence.

for Stokes Q or U. The resulting data set supports a broad range of science goals [4].

The primary science goal is the characterization of primordial gravity waves from an inflationary epoch through measurement of the CMB B-mode power spectrum. PIXIE will measure the CMB linear polarization to sensitivity of 70 nK per $1 \deg \times 1 \deg$ pixel, including the penalty for foreground subtraction. Averaged over the cleanest 75% of the sky, PIXIE can detect B-mode polarization to 3 nK sensitivity, well below the 30 nK predicted from large-field inflation models. The sensitivity is comparable to the "noise floor" imposed by gravitational lensing, and allows robust detection of primordial gravity waves to limit $r < 10^{-3}$ at more than 5 standard deviations (Figure 2).

PIXIE provides a critical test for light dark-matter candidates. Neutralinos are an attractive candidate for dark matter; the annihilation of $\chi\bar{\chi}$ pairs in the early universe releases energy to the CMB and distorts the spectrum away from the blackbody shape. The resulting chemical potential can be estimated as

$$\mu \sim 3 \times 10^{-4} \; f \; \left(\frac{\sigma v}{6 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}}\right) \; \left(\frac{m_\chi}{1 \text{ MeV}}\right)^{-1} \; \left(\Omega_\chi h^2\right)^2 . \tag{VI.2}$$

where f is the fraction of the total mass energy released to charged particles, $\langle\sigma v\rangle$ is the velocity-averaged annihilation cross section, Ω_χ is the dark matter density, and $h = H_0/100 \text{ km s}^{-1} \text{ Mpc}^{-1}$ is the Hubble constant [5,6]. The dark matter annihilation rate varies as the square of the number density. For a fixed Ω_χ the number density is inversely proportional to the particle mass. The chemical potential distortion is thus primarily sensitive to lower-mass particles. PIXIE will probe neutralino mass range $m_\chi < 80$ keV to provide a definitive test for light dark matter models [7].

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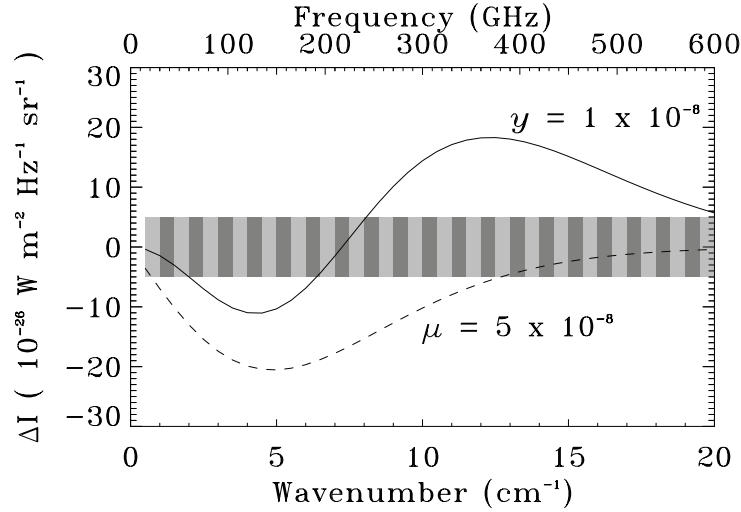
FIG. 10: Distortions to the CMB blackbody spectrum compared to the PIXIE instrument noise in each synthesized frequency channel. The curves show 5σ detections of Compton (y) and chemical potential (μ) distortions. PIXIE measurements of the y distortion determine the temperature of the intergalactic medium at reionization, while the μ distortion probes early energy release from dark matter annihilation or Silk damping of primordial density perturbations.

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CMB Observations: Current Status and Implications for Theory

The aim of this talk was to give an overview of the current state of CMB observations and their scientific implications. This last year has been exciting for this area, mainly as regards CMB observations on small angular scales, i.e. at the high-ℓ part of the CMB power spectrum. Also the Sunyaev-Zeldovich story continues to be very interesting, and the first Planck results have now become available on this.

About 90% of the photons in the CMB reach us directly from decoupling, telling us about the physics at the time of recombination, whilst the rest carry imprints of what happened on the way. Also, when emitted at recombination, the CMB has encoded within it information dating from about 10^{-36} seconds after the big bang. Huge advances in technology over the past few years, are enabling us to measure all three of these aspects with rapidly increasing precision, with the key modern frontiers being *polarization* and *the high resolution temperature power spectrum*.

On the polarization front, the main new results during the past year have come from the QUIET experiment, as reported in [1]. Unlike most other current experiments this uses *coherent* rather than bolometric techniques The feeds look at a 1.4 m primary, and the whole is mounted on the CBI mount in Chile. The results given in [1] are able to confirm the first peak in the EE spectrum first seen in the BICEP experiment [2]. The current direct limit on the primordial tensor to scalar ratio from QUIET is $r < 0.9$ (95%), which is larger than that of $r < 0.73$ given in [2], but they stress that their systematic error in r determination (< 0.1) is the smallest yet, thus promising well for the future measurements (with more data and a further frequency) from QUIET.

The successor to BICEP, BICEP2 was deployed to the South Pole in November 2009. This has 512 detectors at 150 GHz and 8 times the mapping speed of BICEP1 has been achieved, and with similar angular scales and ℓ-range coverage. The latest step is that the *KECK* array is being deployed, which has effectively 5× BICEP2 cryostats [3]. Results from both this and BICEP2 are eagerly awaited.

Results on r and the slope of the power law spectrum of primordial perturbations, n_s, are crucial discriminators of the dynamics of inflationary models. Constraints from WMAP7 [4] in the (r, n_s) plane have already effectively ruled out a purely quartic inflation potential, $V(\phi) \propto \phi^4$, and even $V(\phi) \propto \phi^2$ could be considered to be under some pressure. In these circumstances it is interesting to note that potentials of the form $V(\phi) \propto \phi^p$ with $p \leq 1$ are now starting to be of interest in string cosmology-inspired inflation scenarios. For example, [5] discusses three different types of *monodromy*-type theory (this is where a *shift symmetry* in the theory is able to suppress higher-order corrections to the potential) within string theory, each leading to a $p \leq 1$. A further way in which the looming constraints on monomial potentials can be avoided is via *mixtures* of terms, such as would occur if using the spontaneous symmetry breaking-type potential, of the form $(\phi^2 - v^2)^2$, for v a constant. Terms of this form are thought to arise within a supergravity-type approach to inflation, and their observational consequences are discussed in [6].

Returning to experiments, the prospects for the balloon-borne Spider experiment are discussed in [7]. This experiment has now returned to the idea of medium duration flights around Antarctica, rather than ultra-long flights along a line of latitude through Australia. The first full flight is scheduled for December 2012, and will provide a sky coverage fraction of $f_{\rm sky} \sim 0.1$ and probe the multipole range $10 \leq \ell \leq 300$ with the greatest sensitivity coming at 150 GHz. The maps from Spider could be of great interest as providing B-mode observations which can be combined with those from the Planck Satellite. The latter experiment is still on course to provide first cosmological information in January 2013, with the first release of primordial CMB polarization data likely in January 2014.

A major highlight over the past year has been the release of high-ℓ power spectrum results from both the Atacama Cosmology Telescope (ACT), and the South Pole Telescope (SPT). The talk by Jo Dunkley described the ACT results, and we concentrate here on those from the SPT, as described in the impressive recent paper from Keisler *et al.* [8]. This described results from 790 square degrees of sky measured at 150 GHz, and displays a CMB power spectrum in which 9 peaks can now be clearly discerned. The high-ℓ part of the CMB spectrum now gives a lever arm in which (as for results for the ACT experiment) for the first time various degeneracies in cosmic parameters can be resolved using CMB-alone data. Additionally, various parameters sensitive to the high-ℓ part of the spectrum, such as (a) the tilt of the primordial spectrum, n_s; (b) a possible running in the primordial spectrum, parameterised by $n_{\rm run}$; (c) the primordial Helium abundance Y_p; and (d) the effective number of neutrino species at decoupling, $N_{\rm eff}$, are all starting to be constrained by the data. The basic observational result [8], seems to be that there is a preference for models with slightly more damping at smaller scales than would be predicted with currently favoured values of these

parameters, although with a strong degeneracy affecting what it is possible to say individually about each of $n_{\rm run}$, Y_p and $N_{\rm eff}$ alone.

A further highlight of the year has been the first release of Planck results for the Sunyaev-Zeldovich (SZ) effect in clusters of galaxies. The resolution of Planck for SZ studies (at best $\sim 5'$) is lower than for most ground-based observations, but is compensated for by all-sky coverage, plus a good frequency discrimination of the effect due to multiple frequency channels spanning the whole range over which the effect is important. The 'Early Release SZ Catalogue' (ESZ) [9] contained a sample of 189 clusters of which 169 were previously known. Amongst the new clusters was a candidate which turned out, following XMM-Newton confirmation, to be the first *super*cluster to be detected via the blank-field SZ effect. Other telescopes have now confirmed some of the other candidates, including the observations by the Arcminute MicroKelvin Imager in Cambridge, which was able to provide confirmation within the ESZ paper for a previously unknown cluster, and has done the same for another subsequently [10], as well as providing a refined position estimate.

The story on the SZ 'deficit' discussed in last year's summary, which drew attention to the factor of between 0.5 and 0.7 by which the SZ decrements measured by WMAP7 were below what was expected for the given clusters using standard X-ray models for temperature and profile, [4], has taken an interesting turn in that for the much larger sample surveyed by Planck, no such effect has been found. This is discussed in [11], where additionally to emphasising that no deficit has been found, it is pointed out that even when the analysis is redone in two bins, with pressure profiles corresponding to 'cool cores' or 'morphologically disturbed' (respectively) then the results are still robust to this, with maximum deviations at only the few percent level. Since this division was thought to be important in explanation of the WMAP7 results, [4], it is unclear currently how to explain the apparent discrepancy in findings, and suggests that there is still quite a bit to learn in this area.

Finally, returning to early universe cosmology, the Lasenby & Doran model [12] is still doing surprisingly well in comparison to observations. This model has a slightly closed universe, in which constraints on both the initial and final development of the universe have to be obeyed, and which links the two via an overall constraint on the elapse of total conformal time. This link is able to provide a numerical estimate of the value of the current cosmological constant in terms of an exponential of the number of e-folds of inflation, thus obtaining a very small number (10^{-122}) in natural units, from one not so far from unity (~ 50). In [13], the model is compared with other current models, such as ΛCDM with a power law initial spectrum and the addition of either spatial curvature or a running spectral index, and shown to outperform these in terms of Bayesian evidence, probably through having both a naturally occurring dip in the predicted primordial spectrum at large scales, and also fitting the high-ℓ CMB spectrum better.

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James Webb Space Telescope and the Origins of Everything - Progress and Promise

Abstract. James E. Webb built the Apollo program and led NASA to a successful moon landing. We honor his leadership with the most powerful space telescope ever designed, capable of observing the early universe within a few hundred million years of the Big Bang, revealing the formation of galaxies, stars, and planets, and showing the evolution of solar systems like ours. Under study since 1995, it is a project led by the United States National Aeronautics and Space Administration (NASA), with major contributions from the European and Canadian Space Agencies (ESA and CSA). It will have a 6.6 m diameter aperture (corner to corner), will be passively cooled to below 50 K, and will carry four scientific instruments: a Near-IR Camera (NIRCam), a Near-IR Spectrograph (NIRSpec), a near-IR Tunable Filter Imager (TFI), and a Mid-IR Instrument (MIRI). It is planned for launch in 2018 on an Ariane 5 rocket to a deep space orbit around the Sun - Earth Lagrange point L_2, about 1.5×10^6 km from Earth. The spacecraft will carry enough fuel for a 10 yr mission.

International Partnership. Goddard Space Flight Center leads the NASA team, and is supported by a prime contract to Northrop Grumman Aerospace Systems and their subcontractors, including ATK, Ball Aerospace, and ITT. The NIRCam comes from the University of Arizona with Lockheed Martin. The NIRSpec comes from ESA with Astrium, and its microshutter array is provided by Goddard Space Flight Center. The Fine Guidance Sensor and the Tunable Filter Imager come from CSA with Comdev. All of the near IR detectors come from Teledyne. The mid IR instrument is built by a European consortium led by the UK ATC, in partnership with Jet Propulsion Laboratory, and its detectors come from Raytheon. Europe is also providing the Ariane 5 rocket.

Scientific Objectives. A project summary has been published by Gardner et al. [1]. Additional documents about JWST are available here: http://www.jwst.nasa.gov/ and here: http://www.stsci.edu/jwst/doc-archive. A recent meeting "Frontier Science Opportunities with the James Webb Space Telescope" was held at the Space Telescope Science Institute and the webcast archive is available online: http://www.stsci.edu/institute/conference/jwst2011. Four key topics were used to guide the design of the observatory:

The end of the dark ages: first light and reionization. This theme requires the largest feasible infrared telescope, since the first objects of the universe are faint, rare, and highly redshifted. It requires a wide wavelength range, to distinguish high-redshift objects from cool local objects, and to estimate the ages and photometric redshifts of the stellar contents from colors. It also requires powerful multi-object infrared spectroscopy, to determine the physical conditions and redshifts of the earliest objects.

The assembly of galaxies. It is now thought that galaxies form around dark matter concentrations, as products of extensive merger trees, but it is difficult to tell whether simulations match observations. The interaction between dark matter, ordinary matter, black holes (when and how did they form?), stars, winds, and magnetic fields is extraordinarily complex "gastrophysics". It is currently impossible to simulate the full dynamic range from stars and planetary systems to magnetized jets, outflows, dust formation, etc., so the formation and assembly of galaxies is still an observational science. With its infrared imaging and spectroscopy, JWST will reveal details of galactic mergers and show changes of properties with distance (time).

The JWST will also address some aspects of dark energy and dark matter. It can extend the Hubble measurements of distant supernovae, achieving greater precision by using rest-frame IR photometry, where the candles are more standard and the dust obscuration is less than at visible wavelengths. It can also improve the calibration of the Hubble constant, by extending the range of each step of the distance ladder and eliminating some steps. It can also extend maps of the dark matter distribution to higher redshift, because it can observe many more faint and higher redshift background galaxies than current observatories.

The birth of stars and protoplanetary systems. Local star and planet formation is uniquely observable in the infrared, because of the low temperatures of young objects, and their typical location within obscuring dust clouds. Infrared observations complement radio observations very well.

Planetary systems and the origins of life. Traces of the formation of the Solar System are found everywhere from the bright planets to the faint comets, asteroids, and dwarf planets of the outer solar system. JWST's image quality, field of view, and ability to track moving targets are essential to detect and analyze many such targets, In addition, transit spectroscopy and direct imaging of extra-solar planetary systems are feasible, especially now that the Kepler observatory has cataloged 1235 candidate transiting planets. With the discovery of a favorable nearby target (small star, large Earth), it may be possible to measure the atmospheric composition of an Earth-like planet and to detect the presence of liquid water.

Observatory Design. The observatory is composed of a deployable telescope, a scientific instrument package, and a spacecraft bus, separated by a deployable sun shield to enable the telescope and instruments to cool to < 50 K.

Telescope. The telescope uses a three-mirror anastigmat design to provide a wide field of view with diffraction-limited imaging at 2 μm. The primary is nearly parabolic with an aperture of 6.6 m, and is composed of 18 hexagonal segments. These segments are made of beryllium, machined to a few mm thickness with stiffening ribs, and polished at room temperature to a shape that will be nearly ideal (20 nm rms error) at the operating temperature. All the segments have been polished and coated with gold. The primary mirror segments are deployed after launch and adjusted to the right position and curvature by actuators having step sizes of a few nm. The secondary mirror is also deployed after launch. The final focus is determined using wavefront sensing algorithms, based on star images taken in and out of focus. These algorithms were derived from those used for the Hubble Space Telescope repair. The predicted image quality (point spread function) is available online at http://www.stsci.edu/jwst/software/webbpsf. A small movable flat mirror located at an image of the primary mirror (a fine steering mirror) is used to null the image motion as sensed by the fine guidance sensor in the instrument package; a signal from its control loop also goes to help maintain the pointing of the whole spacecraft,

Instrument Package. All of the instruments are mounted to a carbon-fiber structure attached to the back of the telescope. The near IR camera covers 0.6 to 5 μm in two bands observed simultaneously, with 0.034 and 0.068 arcsec pixels respectively. The camera includes the wavefront sensing equipment, and a coronagraph. The near IR spectrometer provides low (R 100) and medium (R 1000 and 3000) spectroscopy. It can observe 100 simultaneous targets with a microshutter array selector, and also provides fixed slits and an image slicing integral field configuration. The fine guidance sensor is a two-field camera that provides error signals to the pointing control system. The tunable filter imager provides high contrast imaging and spectroscopy in the near IR band. All of the near IR instruments use HgCdTe detectors. The mid IR instrument provides imaging, coronography, and integral field spectroscopy from 5 to 28 μm, using Si:As detectors. The exposure time calculator is available on line at http://jwstetc.stsci.edu/etc. With long exposures, nJy sensitivities are possible (AB magnitude > 31.4).

Spacecraft. The spacecraft bus includes the command and telemetry system, a deployable telemetry antenna, a pointing control system, a solar power system, and a deployable 5-layer sunshield the size of a singles tennis court. Behind the shield, the instrument package and the telescope radiate heat to the dark sky and reach temperatures of 40-50 K, cold enough for operating all the near IR (< 5 μm) detectors. A helium compressor provides active cooling for the mid IR instrument to operate below 7 K, without stored cryogens. Pointing control is provided by reaction wheels and thrusters controlled by sun sensors, gyros (no moving parts!) and star trackers.

Orbit and Orientation. The Ariane 5 launch vehicle will ascend from Kourou, French Guiana, to place the observatory in orbit around the Sun-Earth Lagrange point L_2, approximately 1.5×10^6 km from Earth. Bi-propellant thrusters will adjust the orbit to stay within several hundred thousand km of the L_2 point (which is near the end of the Earth's umbra), and to avoid shadows from the Moon or the Earth. The orbit is unstable and small adjustments will be required every few weeks. Fuel is also required to maintain the orientation of the observatory; small torque unbalances from the solar radiation pressure build up and must be compensated with thruster firings. The fuel tanks are sized to last for 10 years of operation after initial observatory checkout.

Operations. The scientific operation of the JWST will be very similar to that of the Hubble Space Telescope, based on observing proposals evaluated by time allocation committees. Approximately 1/2 year of observations are allocated to the instrument teams and the interdisciplinary scientists. The European share of general observation time is to be 15% and the Canadian share 5% based on their contributions to the mission. It will take about 2 months to reach the L_2 orbit and cool down to operating temperature, and 4 more months are allocated for initial setup, focussing, characterization, and optimization of the observatory.

Project Status. Two of the flight instruments (MIRI and NIRSpec) are completed and tested in Europe, and all four are to be delivered to Goddard Space Flight Center within a year, for integration into the Integrated Science Instrument Module, and combined testing with a telescope simulator. Also, all the flight telescope mirrors (18 primary mirror hexagons, and the secondary, tertiary, and fine steering mirror) have been polished and coated with thin layers of IR-reflecting gold. The near IR detectors (HgCdTe made by Teledyne) were degrading while they were kept warm, the cause has been determined, and new part designs are being made.

Replan. Following two major reports (TAT and ICRP) chaired by John Casani a year ago, the JWST management has been replaced at both Goddard Space Flight Center and NASA Headquarters, and the project has been replanned for a launch date in 2018. The new plan provides additional funds for risk reduction and testing and raises JWST to one of NASA's top three priorities, along with commercial crew and the space launch system (SLS). The NASA budget for 2012 is currently under discussion by the US Congress.

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Status of the theory of neutrino mass and mixing

Essentially, the theory of neutrino mass and mixing does not exist yet. We even do not know what is nature of neutrino mass: Dirac or Majorana, soft (enviroment-dependent) or hard; we do not know the absolute mass scale; number of neutrinos, *etc.*. There are direct and possibly indirect connections between neutrinos and Dark matter (DM - the main subject of this school). Known active neutrinos compose hot component of the dark matter influencing structure formation in the Universe. New neutrino states (sterile neutrinos), if exist, can form, depending on mass, hot or warm component of DM. Concerning indirect connection, the same flavor symmetries which explain the mixing pattern of light neutrinos can also ensure stability of DM particles. Mechanisms of neutrino mass generation imply existence of new particles, e.g. RH neutrinos, which can play the role of DM. Again, symmetry responcible for smallness of neutrino mass can lead to stability of the DM particles.

The most important observational features which play role in uncovering of the origin of neutrino mass include the following. (i) Cosmological and oscillation data show that at least one neutrino mass should be in the interval (0.04 - 0.30) eV. Smallness of neutrino mass can be characterized by ratio $m_\nu/m_\tau \sim 10^{-10}$ which can be connected to some other mass hierarchy. (ii) Neutrinos have the weakest mass hierarchy (if any) which may be related to large lepton mixing. (iii) The lepton mixing pattern is described aproximately by the Tri-Bimaximal (TBM) scheme [1] according to which $\sin^2 \theta_{23} = 1/2$, $\sin^2 \theta_{12} = 1/3$ and $\sin^2 \theta_{13} = 0$. (iv) Global fit of the oscillation data [2] shows substantial deviations from TBM: $1/2 - \sin^2 \theta_{23} = 0.08$ (which is about 2σ off); $1/3 - \sin^2 \theta_{12} = 0.02$ (2σ off) and $\sin^2 \theta_{13} = 0.020 - 0.025$ (3σ off).

Understanding neutrino mass and mixing is on cross-roads. Smallness of neutrino mass can be due to existence of
- New large mass scale, which is realized in the seesaw mechanism.
- Extra spatial dimensions; here the smallness is explained by the overlap mechanism and different localization of the left and right handed components of neutrinos. It is given by ratio of the width of the 3D brane and size of extra dimension or by large warp factor. These two mechanisms are related to properties of the RH neutrinos, they explain simultaneously suppression of the usual Dirac mass terms and finite mass.
- New symmetries which forbid the neutrino Dirac mass term (this also can be due to absence of the RH components). Here finite neutrino masses can be generated by radiative corrections or high dimensional operators.

There are three different approaches to explain the lepton mixing:
1. Tri-bimaximal mixing [2] as the first order approximation. If not accidental, TBM implies certain flavor (fundamental) symmetry [3]. The symmetry should be broken differently in the charged lepton and neutrino sectors. Different residual symmetries are responcible for the TBM mixing.
2. Quark-lepton complementarity [4] is based on observation that the lepton mixing equals approximately bimaximal mixing (*i.e.* maximal 1-2 and 2-3 mixings) minus quark mixing. This implies the quark-lepton unification or quark-lepton symmetry and existence of some new structures or interactions which generate the bi-mimimal mixing. The latter can be the see-saw machanism and specifically certain pattern of the Majorana mass matrix of RH neutrinos.
3. Quark-lepton universality means that the lepton mixing is organized according to the same principle as quark mixing. Probably mixing angles are related to the mass hierachies. Large lepton mixing is due to the smallness of neutrino mass and weak mass hierarchy of neutrinos. The same mechanism which explains the smallness of neutrino masses is responsible for enhancement of the lepton mixing. Again usual see-saw can be behind this picture.

Probably correct approach is go as far as possible along the quark and lepton unification and reduce to minimum features/principles which distinguish quarks and leptons. Neutrality of neutrinos and therefore possibility to have Majorana mass are the key points. Following this line one can chose GUT based on $SO(10)$ with all the known fermions (plus RH neutrinos) in the same 16-plet. The singlets of SO(10) may exist and mix with neutrinos only, and it is this mixing which produces difference between lepton and quark mixings and explains smallness of the neutrino mass.

TBM can be accidental without any fundamental symmetry and principle behind; e.g. it can be an interplay of different independent contributions [5]. Due to observed deviations of mixing from TBM the symmetry relations between the elements of neutrino mass matrix can be broken maximally. No simple and convincing model for TBM has been proposed so far. Models have complicated structure and large number of assumptions and free parameters. Often no connection between masses and mixing exists and additional symmetries are introduced to explain mass hierarchies. Inclusion of quarks leads to further complication. Grand unification imposes additional requirements.

The latest measurements of 1-3 mixing [6] further support this point of view, favouring the possibilities 2 and 3. Indeed, too small value of this mixing, $\sin\theta_{13} \sim \sin^2\theta_C$, is typical prediction of the flavor-symmetry models of TBM [3]. On the other hand according to the Quark-lepton complementarity $\sin^2\theta_{13} \approx 2\sin^2\theta_C$, which is close to the observed value [4]. Typical GUT prediction without special symmetry in the leptonic sector is $\sin^2\theta_{13} \sim \Delta m_{21}^2/\Delta m_{31}^2$ [7], again in a good agreement with data.

For further progress in theory of neutrino mass and mixing it is important to settle down the issue of existence of sterile neutrinos. Variety of sterile neutrinos has been proposed with masses in different energy ranges from 10^{-3} eV to 10^2 MeV. Some new hints in favour of the eV-scale (LSND) ν_S follow from MiniBooNE results, reactor anomaly and Gallium calibration experiments [8], [9]. Furthermore, Cosmology (mainly CMB) indicates existence of additional radiation in the Universe. Actually Cosmology "likes" additional but light neutrinos [10]: for single ν_S it gives the bound $\Delta m^2 < 0.25$ eV^2. Toghether with new MINOS bound on mixing [11] this essentially excludes the oscillation interpretation of the results from LSND and MiniBooNE.

Mixing of the eV-scale neutrino with light neutrinos with mixing angles required by LSND is not a small perturbation. The corresponding contribution to the light neutrino mass matrix, δm, can be larger than the original elements m_0. δm can change structure (symmetries) of the original mass matrix completely. It can produce the dominant $\mu - \tau$ block with small determinant, enhance the lepton mixing, generate TBM, be origin of difference of the quark and lepton mixings.

IceCube can perform very sensitive search for the LSND-type sterile neutrinos. The $\nu_\mu - \nu_s$ oscillations with $\Delta m^2 \sim 1$ eV^2 are enhanced in matter of the Earth in the energy range $0.5 - 3$ TeV [12]. This distorts the energy spectrum and zenith angle distribution of the atmospheric muon neutrinos. Effect on the zenith angle distribution integrated over the neutrino energy is about $(10-20)\%$ [13]. Statistics is not the problem for IceCube: it has already about 10^5 neutrino events and the main goal is to understand systematics. The effect in IceCube depends not only on admixture of ν_μ in the heavy, mainly sterile state, $U_{\mu 4}$, but also on admixture of ν_τ, $U_{\tau 4}$. Part of the parameter-space formed by m_S, $U_{\mu 4}$ and $U_{\tau 4}$ can be excluded with already existing data [13].

Another interesting scenario is sterile neutrino with very small mass: $m_S \sim 10^{-3}$ eV [14]. Being mixed with ν_e this neutrino can explain the absence of expected upturn of the energy spectrum of solar neutrinos at low energies. If it mixes with the heaviest mass eigenstate, ν_3, the equilibrium concentration of ν_S can be generated in the Early Universe thus producing additional radiation without creating problem for Large scale structure of the Universe. Existence of such a sterile neutrino can be tested in the DeepCore experiment studying the zenith angle and energy distributions of the atmospheric neutrinos [14].

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Helioseismology, Neutrinos and Dark Matter

The Sun is certainly the best known star. But answers to crucial questions are still missing because its standard representation is too poor to reproduce all the present observations. We ignore its initial mass and consequently the real history of the formation of Earth and Mars: we know already that its initial mass was larger than the present one to avoid what has been called the 'Solar paradox' [1]. We cannot predict its degree of activity for the next 20 years and its impact on the present Earth environment because its internal magnetic description is not yet under control. All these questions emerge once again because the knowledge of the solar interior has been improved tremendously this last 10 years thanks to the SoHO satellite that transforms it in a real laboratory of plasma physics. One needs to explain properly the present sound speed profile and the present internal rotation profile. They are now really under control and they show the limitations of the standard solar model [2,3]. See Figure 1.

A large success of the last decade is that all the different informations: detected solar neutrinos of different flavors or energies, acoustic modes, gravity modes altogether lead to a coherent and new picture of our active star [4].

So, this star can also put some constraints on the properties of dark matter due to the position of the Sun in our Galaxy and the accuracy obtained in the whole radiative zone that contains practically 98% of the solar mass [5,6,7].

In fact, the idea that the Sun could show an indirect evidence of dark matter appears in the eighties [8] to solve the 'solar neutrino problem' with a CDM scenario. In this contribution we show how this idea has evolved, how WIMPs could have imprinted the solar core and how the range of WIMPs properties are reduced by the recent detection of gravity modes associated to boron neutrino detection. We finally discuss quickly also the case of the potential presence of lighter particles like sterile neutrinos of the keV range in the solar interior.

Neutrinos, Acoustic modes and Gravity modes

The accumulation of WIMPS in the center of the Sun decreases the central temperature and increases the density. These WIMPS rapidly become in thermic equilibrium with baryons (Hydrogen, Helium and other elements), leading to the formation of an isothermal core that modifies the sound speed and density profiles below 5% $R_{\odot}$ [5].

The best way to check this possibility is to use the boron neutrino flux that is extremely dependent on the central temperature (to the exponent 20-24) and to detect gravity modes that add some independent constrains on the central density and its profile in the core below 0.1 $R_{\odot}$. Both are now available after 30 years of effort.

The SNO boron detection [9,10] has completed the Kamiokande results and totally clarified the fact that different flavors of neutrinos must be considered to understand all the detections of the solar boron neutrino emitted flux (the flux coming from the reaction p+Be7 -> $B8^*$ -> 2 He4 + e^+ + ν_e that acts in the first 10% $R_{\odot}$.

In parallel the use of a large number of acoustic modes detected aboard the SOHO satellite [2a] and confirmed with ground instruments [2b] has allowed to build a seismic solar model that avoids the variability of the standard model prediction of the boron flux noticed along time (see Table 6 of [4]). This point is important because, as mentioned previously, we know today that the physics of the standard model is incomplete. The seismic model is built to get practically no difference in sound speed between model and observation (Fig 1a). The acoustic modes detection allows an observational estimate of the sound speed down to 0.06 $R_{\odot}$ with a vertical error bar extremely small. One sees on the figure that the difference with SSM sound speed integrating the recent composition of CNO is larger at more than 25 σ from the observational result.

The main characteristics of this seismic model [2, 11,12] are summarized in Table 1. This model allows a prediction of the gravity mode frequencies that are in very good agreement with the first observation of dipole gravity modes ([3,13] and Figure 1b). Their period differences are smaller than 0.3 minute. It also produces results in agreement with the detection of all the different neutrino installations (see table 9 of [4]). So the central temperature, central density and core density profile of the Sun must be very near from those of the seismic model predictions, even the detailed physics of the radiative zone is not totally under control: possible existence of a fossil field, possible bad determination of the transfer of energy, possible effect of dark matter...

Constraints on Cold Dark Matter or Warm Dark Matter

We use these previous strong constraints to limit the range of parameters of the WIMPs properties using the prescription of [14] that introduces a capture, annihilation and evaporation rates. We show that the new solar detections cannot constrain dark matter annihilation models as the estimated cross section is too small to produce any effect on the density profile. But we exclude the presence of non-annihilating WIMPs in the Sun for masses $\leq$ 10 GeV and spin dependent cross sections > $5\,10^{-36}$ cm^2 [7], see Figure 1b. No signature is visible in the obtained
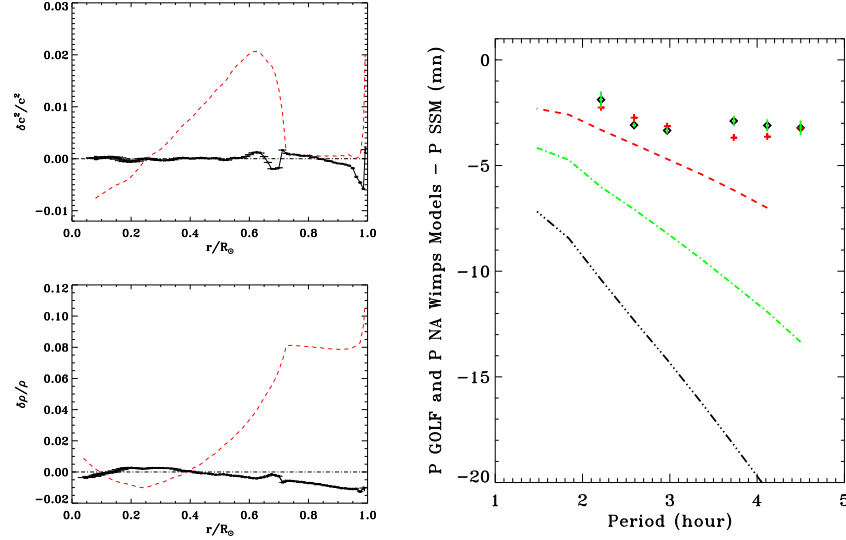
FIG. 11: Left: Differences in squared sound speed between GOLF+MDI/SoHO and solar model predictions. Seismic model: full line + seismic error bars, blue (−−) and red lines (small −−) from SSM models without or with tachocline treatment. From [4]. Right: Differences in minutes between GOLF (green diamonds with error bars) or SSeM (crosses) and SSM gravity mode periods. Superimposed are the differences for solar model with DM using spin dependent cross section of $5\ 10^{-36}$cm^2 for respectively 5, 7 and 10 Gev (black −...− line, green −.− line and red small −− line). From [7].

TABLE II: Central conditions of the seismic model

T_C	ρ_C	boron ν prediction	gravity mode prediction l= 2, n = -10
15.75 10^6K	153.6 g/ cm^3	5.31 $\pm$0.6 $10^6\nu/cm^3$	62.50 μHz

profile in the solar core. We note also that the seismic model has a central temperature higher than the SSM (T_C= 15.51, SSM neutrino prediction is not compatible with boron neutrino detection) but a density slightly smaller by 2 or 3%. This remark could favor other kinds of processes like a different gravitational effect due to WDM (sterile neutrinos ?) acting on the whole radiative zone. In fact the radiative zone is certainly more complex than thought previously and one needs to include a good energetic balance [1] and all the potential dynamical effects before any conclusion on this subject.

In the coming years helio- and asteroseismology will provide complementary results to extend the present study and to check these probes of dark matter.

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VII. POSTERS HIGHLIGHTS

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Light sterile neutrino as warm dark matter and the structure of galactic dark halos

Abstract

We study the formation of nonlinear structure in Λ Warm Dark Matter (WDM) cosmology using large cosmological N-body simulations. We assume that dark matter consists of sterile neutrinos that are generated through nonthermal decay of singlet Higgs bosons near the Electro-Weak energy scale. Unlike conventional thermal relics, the nonthermal WDM has a peculiar velocity distribution, which results in a characteristic shape of the matter power spectrum. We perform large cosmological N-body simulations for the nonthermal WDM model. We compare the radial distribution of subhalos in a Milky Way size halo with those in a conventional thermal WDM model. The nonthermal WDM with mass of 1 keV predicts the radial distribution of the subhalos that is remarkably similar to the observed distribution of Milky Way satellites.

Introduction

Alternative models to the standard Λ Cold Dark Matter model have been suggested as a solution of the so-called 'Small Scale Crisis'. One of them is Λ Warm Dark Matter cosmology, in which Dark Matter particles had non-zero velocity dispersions. The non-zero velocities smooth out primordial density perturbations below its free-streaming length of sub-galactic sizes. The formation of subgalactic structure is then suppressed. Moreover, The large phase space density may prevent dark matter from concentrating into galactic center. Particle physics models provide promising WDM candidates such as gravitinos, sterile neutrinos and so on. Gravitinos with mass of $\sim$keV in generic Supergravity theory are produced in thermal bath immediately after reheating and are then decoupled kinematically from thermal bath similarly to the Standard Model (SM) neutrinos because gravitinos interact with SM particles only through gravity. The thermal relics have a Fermi-Dirac (FD) momentum distribution. Sterile neutrinos are initially proposed in the see-saw mechanism to explain the masses of the SM neutrinos. If the mass of sterile neutrinos is in a range of $\sim$keV and their Yukawa coupling is of order $\sim 10^{-10}$, then it cannot be in equilibrium with SM particles throughout the thermal history of the universe. There are several peculiar production mechanisms for sterile neutrinos, such as Dodelson-Widrow (DW) mechanism [1] and EW scale Boson Decay (BD) [2]. In DW mechanism, sterile neutrinos are produced through oscillations of active neutrinos, and its velocity distribution has a Fermi-Dirac form just like gravitinos. In the BD case, sterile neutrinos are produced via decay of singlet Higgs bosons and they have generally a nonthermal velocity distribution. The nonthermal velocity distribution imprints particular features in the transfer function of the density fluctuation power spectrum [3]. The transfer function has a cut-off at the corresponding free-streaming length, but it decreases somewhat slowly than thermal WDM models. In this article, we study the formation of nonlinear structure for a cosmological model with nonthermal sterile neutrino WDM. We perform large cosmological N-body simulations. There are several models of nonthermal WDM. For example, gravitinos can be produced via decay of inflaton [4] or long-lived Next Lightest Supersymmetric Particle (NLSP) [5]. Our result can be generally applied to the formation of nonlinear structure in these models as well.

Nonthermal sterile neutrino

The clustering properties of the above BD sterile neutrino model is investigated by Boyanovsky [3], who solved the linearized Boltzmann-Vlasov equation in the matter dominant era when WDM has already become non-relativistic. Firstly, solving the Boltzmann equation for sterile neutrinos produced by the singlet boson decay process, we find the most of contribution to the present number of sterile neutrinos comes when the temperature decreases to the EW scale. We then get the velocity distribution of sterile neutrinos. The BD distribution has a distinguishable feature from usual Fermi-Dirac distributions at small velocities, $y = P/T(t)$:

$$f_{\mathrm{BD}}(y) \propto \frac{1}{y^{\frac{1}{2}}}, \qquad f_{\mathrm{FD}}(y) \propto 1.$$

The velocity distribution is imprinted in the power spectrum, which decreases slowly across the free-streaming length scale. Following Boyanovsky [3], we solve the linearlized Boltzmann-Vlasov equation. We define the comoving free-streaming wavenumber as

$$k_{\mathrm{fs}} = \Big[\frac{3H_0^2 \Omega_M}{2\langle \vec{V}^2 \rangle(t_{\mathrm{eq}})} \Big]^{\frac{1}{2}}$$

akin to the Jeans scale at the matter-radiation equality. In the BD case, the present energy density of dark matter is determined by the Yukawa coupling. Assuming the relativistic degree of freedom $\bar{g}$ is the usual SM value $\bar{g} \simeq 100$ for the $m = 1$ keV sterile neutrino dark matter, we find

$$k_{\rm fs}^{\rm BD} = 18 \; h \; {\rm Mpc}^{-1},$$

while for the $m = 1$ keV gravitino dark matter, which has the FD distribution, we should take $\bar{g} \simeq 1000$ to get the present energy density of dark matter. Then, for $m = 1$ keV gravitinos,

$$k_{\rm fs}^{\rm FD} = 32 \; h \; {\rm Mpc}^{-1}.$$

Although these two models have almost the same free-streaming length, their linear power spectra show appreciable differences, as seen in Fig. 1. There, we adopt the numerically fit transfer function in Bode et al. [6] for the linear power spectrum of the gravitino dark matter.

The enhancement of the velocity distribution in the low velocity region leads to the slower decrease of the linear power spectrum. This implies that we should care not only free-streaming scale or velocity dispersion, but also the shape of the velocity distribution in studying the formation of the nonlinear object below the cut-off (free-streaming) scale.

Using these linear power spectrum, we have performed direct numerical simulations to study observational signatures of the imprinted velocity distribution in the subgalactic structures. We start our simulations from a redshift of $z = 9$. We use $N = 256^3$ particles in a comoving volume of $10 \; h^{-1}$ Mpc on a side. The mass of a dark matter particle is $4.53 \times 10^6 \; h^{-1} \; {\rm M}_\odot$ and the gravitational softening length is $2 \; h^{-1}$ kpc.

Simulation Results

Fig. 2 shows the projected distribution of dark matter in and round a Milky Way size halo at $z = 0$. The plotted region has a side of $2 \; h^{-1}$ Mpc. Dense regions appear bright. Clearly, there are less subgalactic structures for the WDM models. The 'colder' property of the nonthermal WDM shown in the linear power spectrum (see Fig. 1) can also be seen in the abundance of subhalos.

In Fig. 3, we compare the cumulative radial distribution of the subhalos in our 'Milky Way' halo at $z = 0$ with the distribution of the observed Milky Way satellites [7]. Interestingly, the nonthermal WDM model reproduces the radial distribution of the observed Milky Way satellites in the range above ~ 40 kpc. Contrastingly, the CDM model overpredicts the number of subhalos by a factor of 5 than the observed Milky Way satellites. This is another manifestation of the so-called 'Missing satellites problem'. The thermal WDM model surpresses subgalactic structures perhaps too much, by a factor of $2 - 4$ than the observation.

Summary

We have studied the formation of the nonlinear structures in a ΛWDM cosmology using large cosmological N-body simulations. We adopt the sterile neutrino dark matter produced via the decay of singlet Higgs bosons with a mass of EW scale. The sterile neutrinos have a nonthermal velocity distribution, unlike the usual Fermi-Dirac distribution. The distribution is a little skewed to low velocities. The corresponding linear matter power spectrum decreases slowly across the cut-off scale compared to the thermal WDM, such as gravitino dark matter. Both of the two models have the same mass of 1 keV and an approximately the same cut-off (free-streaming) scale of a few $10 \; h \; {\rm Mpc}^{-1}$. We have shown that this 'colder' property of the nonthermal WDM can be seen in richer subgalactic structures. The nonthermal WDM model with mass of 1 keV appears to reproduce the radial distribution of the observed Milky Way satellites.

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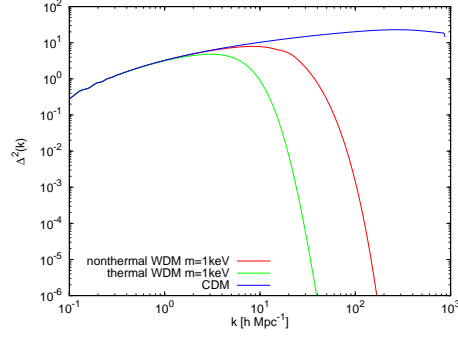
FIG. 12: The linear power spectra for the nonthermal WDM (red line), thermal WDM (green line) and CDM (blue line). The dark matter mass of the both WDM model is $m = 1$ keV.

FIG. 13: The projected distributions of the substructures in our 'Milky Way' halo at $z = 0$. The sidelength of the shown region is $2\ h^{-1}$ Mpc. The results are for three dark matter models, CDM, nonthermal WDM with 1 keV mass and thermal WDM with 1keV mass, respectively, from left to right.
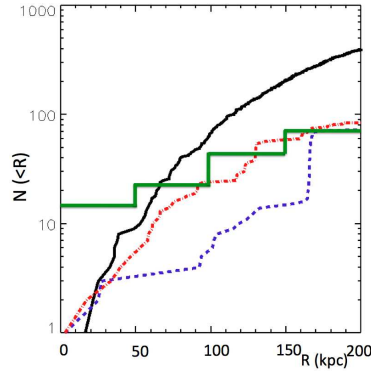
FIG. 14: The radial distribution of the subhalos in our 'Milky Way' halo at $z = 0$. For simulation results for CDM (black), 1keV nonthermal WDM (red), and 1keV thermal WDM (blue). Green bars show the distribution of the observed Milky Way satellites.

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The effects of free streaming on warm dark matter haloes: a test of the Gunn-Tremaine limit

The free streaming of warm dark matter particles dampens the fluctuation spectrum, flattening the mass function of haloes and imprinting a fine grained phase density (PSD) limit for dark matter structures. The Gunn-Tremaine limit is expected to imprint a constant density core at the halo center. In a purely cold dark matter model the fine grained phase space density is effectively infinite in the initial conditions and would therefore be infinite everywhere today. However when the phase space density profiles are computed using coarse grained averages that can be measured from N-body simulations, the value is finite everywhere and even falls with radius with a universal power law slope within virialised structures (Taylor & Navarro 2001). The coarse grained phase space is an average over mixed regions of fine grained phase space, so this behaviour is as expected (Tremaine & Gunn 1979).

Using high resolution simulations of structure formation in a warm dark matter universe (movies available: http://obswww.unige.ch/~paduroiu) we explore these effects on structure formation and the properties of warm dark matter halos.

- The finite initial fine grained PSD is a also a maximum of the coarse grained PSD, resulting in PSD profiles of WDM haloes that are similar to CDM haloes in the outer regions, however they turn over to a constant value set by the initial conditions

- The turn over in PSD results in a constant density core with characteristic size that is in agreement with the simplest expectations

- We demonstrated that if the primordial velocities are large enough to produce a significant core in dwarf galaxies i.e. ~ kpc, then the free streaming erases all perturbations on that scale and the haloes cannot form

- Halo formation occurs top down on all scales with the most massive haloes collapsing first

- The concentration - mass relation for WDM haloes is reversed with respect to that found for CDM

- Warm dark matter haloes contain visible caustics and shells

We ran two suites of simulations, first with a 160^3 particles in 40 Mpc box, and the second one with 300^3 in a 42.51 Mpc box. We adopt a flat ΛCDM cosmology with parameters from the first year WMAP results (Spergel et al. 2003). The transfer function in WDM model has been computed using the fitting formula suggested by Bode, Turok and Ostriker (2001) where α, the scale of the break, is a function of the WDM parameters (Viel et al (2005)), while the index ν is fixed. From these simulations several galaxy mass haloes were re-simulated at higher resolution, with and without thermal velocities. The density profile for a $7 \times 10^{11} M_\odot$ is shown in Figure 15 in four different contexts, the CDM case, the WDM case with just the cutoff in the power spectrum as expected for a 200eV particle (WDM1), with velocities corresponding to the 200eV particle (WDM2), and with velocities artificially increased such that they correspond to a 20eV particle but with the power spectrum of the 200eV case (WDM3).

Figure 2 shows the corresponding coarse grained PSD profiles calculated by spherical averaging the quantity ρ/σ^3.

In the case of our simulations, for a constant density in the initial conditions, the phase space density is:

$$Q_0 = \frac{\rho}{\sigma^3} = \rho_{crit}\Omega \left(\frac{m_\nu c^2}{KTc} \right)^3 \qquad (VII.1)$$

For a critical density $\rho_{crit} = 1.4 \times 10^{-7} M_\odot/pc^3$ and $\Omega = 0.268$ we find the phase space density:

$$Q_0 = 3 \times 10^{-4} M_\odot pc^{-3} (km/s)^{-3} \left(\frac{m_x}{1keV} \right)^3 \qquad (VII.2)$$

The minimum core radius is described by

$$r_{c,min}^2 = \frac{\sqrt{3}}{4\pi G Q_0} \frac{1}{\langle \sigma^2 \rangle^{1/2}}, \qquad (VII.3)$$
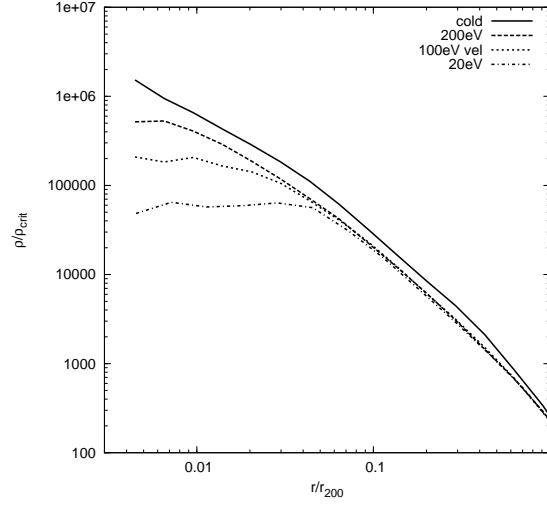
FIG. 15: The spherically averaged density profiles for CDM, WDM1, WDM2 & WDM3 haloes. The resolution limit is at approximately 0.5% of the virial radius (the softening radii are a 0.26% of the virialized radius).
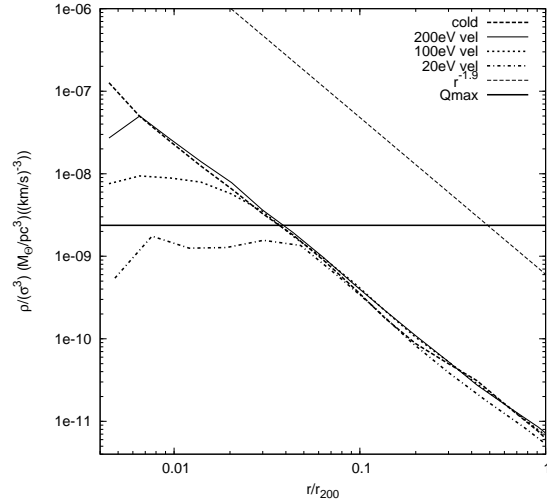
FIG. 16: "Phase-space density" (PSD) profiles of the same haloes shown in Figure 1, calculated using ρ/σ^3.

Thus for a particle with $m_x = 20$ eV and $\sigma = 150$ km/s the phase space density is $2.4 \times 10^{-9} M_\odot \text{pc}^{-3} \, (\text{km/s})^{-3}$ which gives a theoretical value for the core radius of 9.3 kpc. If we consider the core radius to be the radius where the density starts decreasing from the constant value, a "by eye" fit gives a slightly larger radius of 6.5 kpc, while the radius where the density drops by a factor of 2 is 9.4 kpc in agreement with the theoretical predictions.

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VIII.   SUMMARY AND CONCLUSIONS OF THE COLLOQUIUM BY H. J. DE VEGA, M.C. FALVELLA AND N. G. SANCHEZ

A.   General view and clarifying remarks

Participants came from Europe, North and South America, Russia, Ukraine, Japan, India, Korea. Journalists, science editors and representatives of the directorates of several agencies were present in the Colloquium. Discussions and lectures were outstanding. The Standard Model of the Universe was at the center of this Colloquium with the last novelties in the CMB data, high multipoles, CMB lensing detection, Sunayev-Zeldovich measurements and their scientific implications, warm dark matter (WDM) advances with both theory and observations, neutrino masses and neutrino oscillations, keV sterile neutrinos as serious WDM candidates, with both theory and experimental search, heliosismology progresses, galaxy observations, clusters and structure formation, the structure of the interstellar medium and star formation, and the links between these subjects, mainly through gravity and dark matter forming the structures of the cosmic web with the present vaccum energy being the cosmological constant (dark energy). Warm dark matter research evolve fastly in both astronomical, numerical, theoretical, particle and experimental research. The Colloquium allowed to make visible the work on WDM made by different groups over the world and cristalize WDM as the viable component of the standard cosmological model in agreement with CMB + Large Scale Structure (LSS) + Small Scale Structure (SSS) observations, ΛWDM, in contrast to ΛCDM which only agree with CMB+LSS observations and is plagued with SSS problems.

The participants and the programme represented the different communities doing research on dark matter:

- Observational astronomers

- Computer simulators

- Theoretical astrophysicists not doing simulations

- Physical theorists

- Particle experimentalists

WDM refers to keV scale DM particles. This is not Hot DM (HDM). (HDM refers to eV scale DM particles, which are already ruled out). CDM refers to heavy DM particles (the so called wimps at the GeV scale or with any mass scale larger than the keV).

It should be recalled that the connection between small scale structure features and the mass of the DM particle follows mainly from the value of the free-streaming length l_{fs}. Structures smaller than l_{fs} are erased by free-streaming. WDM particles with mass in the keV scale produce $l_{fs} \sim 100$ kpc while 100 GeV CDM particles produce an extremely small $l_{fs} \sim 0.1$ pc. While the keV WDM $l_{fs} \sim 100$ kpc is in nice agreement with the astronomical observations, the GeV CDM l_{fs} is a million times smaller and produces the existence of too many small scale structures till distances of the size of the Oort's cloud in the solar system. No structures of such type have ever been observed.

Also, the name CDM precisely refers to simulations with heavy DM particles in the GeV scale. Most of the literature on CDM simulations, do not make explicit the relevant ingredient which is the mass of the DM particle (GeV scale wimps in the CDM case).

The mass of the DM particle with the free-streaming length naturally enters in the initial power spectrum used in the N-body simulations and in the initial velocity. The power spectrum for large scales beyond 100 kpc is identical for WDM and CDM particles, while the WDM spectrum is naturally cut off at scales below 100 kpc, corresponding to the keV particle mass free-streaming length. In contrast, the CDM spectrum smoothly continues for smaller and smaller scales till ~ 0.1 pc, which gives rise to the overabundance of CDM structures at such scales predicted by CDM.

CDM particles are always non-relativistic, the initial velocities are taken zero in CDM simulations, (and phase space density is unrealistically infinity in CDM simulations), while all this is not so for WDM.

Since keV scale DM particles are non relativistic for $z < 10^6$ they could also deserve the name of cold dark matter, although for historical reasons the name WDM is used. Overall, seen in perspective today, the reasons why CDM does not work are simple: the heavy wimps are excessively non-relativistic (too heavy, too cold, too slow), and thus frozen, which preclude them to erase the structures below the kpc scale, while the eV particles (HDM) are excessively relativistic, too light and fast, (its free streaming length is too large), which erase all structures below the Mpc scale; in between, WDM keV particles produce the right answer.

Discussions and lectures were outstanding. Inflection points in several current research lines emerged. New important issues and conclusions arised and between them, it worths to highlight:

Results and the current state of missions and ongoing projects were reported by their teams: Atacama Cosmology Telescope, Planck, Herschel, SPIRE, ATLAS and HerMES surveys, the James Webb Telescope

B. Conclusions

Some conclusions are:

- *James E. Webb* is honored with the most powerful space telescope ever designed, capable of observing the early universe within a few hundred million years of the Big Bang, revealing the formation of galaxies, stars, and planets, and showing the evolution of solar systems like ours. It is NASA project, with major contributions from the European and Canadian Space Agencies (ESA and CSA). It will have a 6.6 m diameter aperture (corner to corner), will be passively cooled to below 50 K, and will carry four scientific instruments: a Near-IR Camera (NIRCam), a Near-IR Spectrograph (NIRSpec), a near-IR Tunable Filter Imager (TFI), and a Mid-IR Instrument (MIRI). It is planned for launch in 2018 on an Ariane 5 rocket to a deep space orbit around the Sun - Earth Lagrange point L_2, about 1.5×10^6 km from Earth. The spacecraft will carry enough fuel for a 10 yr mission. Four key topics were used to guide the design of the observatory: (i) The end of the dark ages: first light and reionization requires the largest feasible infrared telescope (first objects of the universe are faint, rare, and highly redshifted), a wide wavelength range and a powerful multi-object infrared spectroscopy, to determine the physical conditions and redshifts of the earliest objects.(ii) The assembly of galaxies around dark matter concentrations. The interaction between dark matter, ordinary matter, black holes (when and how did they form), stars, winds, and magnetic fields is extraordinarily complex "gastrophysics". With its infrared imaging and spectroscopy, JWST will reveal details of galaxy formation and evolution. The JWST will also address some aspects of dark energy and dark matter. It can extend the Hubble measurements of distant supernovae; improve the calibration of the Hubble constant; extend maps of the dark matter distribution to higher redshift.(iii) The birth of stars and protoplanetary systems uniquely observed in the infrared which complement radio observations very well.(iv) Planetary systems and the origins of life from the bright planets to the faint comets, asteroids, and dwarf planets of the outer solar system. JWST's image quality, field of view, and ability to track moving targets are essential to detect and analyze many such targets, among other feasible observations with JWST in this topic.

- The *Herschel* Gould Belt survey images the bulk of nearby ($d \sim 500$ pc) molecular clouds in a variety of star-forming environments, allowing to clarify the physical mechanisms of prestellar cores's origin out of the diffuse interstellar medium (ISM), and the stellar initial mass function (IMF)origin. A profusion of parsec-scale filaments in nearby ISM molecular clouds is found and an intimate connection between the filamentary structure and the dense cloud core formation process. Remarkably, filaments are omnipresent even in unbound, non-star-forming complexes and all appear to share a common width ~ 0.1pc:

  In active star-forming regions prestellar cores are located within gravitationally unstable filaments which mass per unit length exceeds the critical value $M_{\mathrm{line,crit}} = 2\, c_s^2/G \sim 15\, M_\odot$/pc, where $c_s \sim 0.2$ km/s is the isothermal sound speed for $T \sim 10$ K. Core formation occurs in two main steps: First, an intricate ISM filaments network is generated by large-scale turbulence ; second, the densest filaments fragment into prestellar cores by gravitational instability.

  This *explains* the star formation threshold at a gas *surface density* $\Sigma_{\mathrm{gas}}^{\mathrm{th}} \sim 130\, M_\odot$ pc^{-2} found recently in both Galactic and extragalactic cloud complexes : Given the typical ~ 0.1 pc width of interstellar filaments, the threshold $\Sigma_{\mathrm{gas}}^{\mathrm{th}}$ corresponds to within a factor of < 2 to the critical mass per unit length $M_{\mathrm{line,crit}}$ above which gas filaments at $T \sim 10$ K are gravitationally unstable.

- Impressive CMB observations and their scientific implications have been reported on small angular scales, i.e. at the high-ℓ part of the CMB power spectrum. Also the Sunyaev-Zeldovich story continues to be interesting. The key modern frontiers being *polarization* and *the high resolution temperature power spectrum*. The current direct limit on the primordial tensor to scalar ratio from QUIET is $r < 0.9$ (95%),thus promising well for the future measurements (with more data and a further frequency) from QUIET. Results on r and n_s, are crucial

discriminators of the dynamics of inflationary models. Constraints from WMAP7 in the (r, n_s) plane have already effectively ruled out a purely (monomial) quartic inflation potential, $V(\phi) \propto \phi^4$, and the monomial $V(\phi) \propto \phi^2$ is under pressure.

High-ℓ power spectra were released from the Atacama Cosmology Telescope (ACT), and the South Pole Telescope (SPT): The CMB power spectrum impressively displays now 9 peaks clearly discerned. Various degeneracies in cosmic parameters can be now resolved with CMB-alone data. The high-ℓ part can also better constraint: (a) the tilt of the primordial spectrum, n_s; (b) a possible running $n_{\rm run}$; (c) the primordial Helium abundance Y_p; and (d) the effective number of neutrino species at decoupling, $N_{\rm eff}$. The small-scale CMB can now be used to probe late-time physics secondary effects.

ACT observed primordial helium at high significance, and detected the CMB lensing (photons gravitationally deflected-a few arcminutes-by large scale structures): lensing directly smooths the acoustic peaks and increases the small-scale power, and couples modes of different scales generating a non-zero lensing 4-point function whose measure led to a 4σ detection of the ACT lensing power: the first direct detection of CMB lensing. The CMB alone can now provide evidence for a dark energy component in the universe.

The amplitudes of the Sunayev-Zeldovich effect in clusters measured by WMAP7 were below a factor of 0.5-0.7 with respect to the standard X-ray models expectations for temperature and profile. However for the much larger sample of clusters surveyed by Planck (first released results) no such deficit has been found. It is unclear currently how to explain the apparent discrepancy in findings, and suggests that there is still quite a bit to learn in this subject. ACT cluster number counts and scaling relations between cluster mass and SZ signal: further multi-wavelength observations are expected to better determine cluster masses and constraints.

The maps from the balloon-borne Spider experiment around Antarctica could be of great interest as providing B-mode polarisation observations which can be combined with those from the Planck Satellite. Planck is still on course to provide first cosmological information in January 2013, with the first release of primordial CMB polarization data likely in January 2014. Results from both the *KECK* array, the BICEP2 in the South Pole and ACTPol are eagerly awaited. ACTPol is due to begin observations in 2012 with improved sensitivity and polarization capabilities to measure the primordial power spectrum in polarization and the improved lensing signal.

- The primordial CMB fluctuations are almost gaussian. The effective theory of inflation à la Ginsburg-Landau predicts negligible primordial non-gaussianity, negligible running scalar index and the tensor to scalar ratio r in the range $0.021 < r < 0.053$, with the best value $\sim 0.04 - 0.05$ at reach of the next CMB observations. Forecasted r-detection probability for Planck with 4 sky coverages is border line. Improved measurements on n_s as well as on TE and EE modes will improve these constraints on r even if a detection will be lacking. Results from Planck are eagerly expected. *Planck* will improve the accuracy of current measures of a wide set of cosmological parameters by a factor from ~ 3 to ~ 10 and will characterize the universe geometry with unprecedented accuracy thanks to its excellent mapping and wide frequency coverage removal which allows all astrophysical emissions. *Planck* will provide information and constraints on the early stages of the universe to the late phases of cosmological reionization, on the neutrino masses and effective species number, the primordial helium abundance, the stochastic field of gravitational waves through the B-mode angular power spectrum of the CMB anisotropies, *Planck* represents also an extremely powerful fundamental and particle physics laboratory.

- Linear polarization of the cosmic microwave background (CMB) provides a direct test of inflation. Gravity waves generated during inflation impart a characteristic curl pattern (B-mode) in the linear CMB polarization. Satisfying the simultaneous requirements of sensitivity, foreground discrimination, and immunity to systematic errors to detect such signal is a technological challenge. The Primordial Inflation Explorer (PIXIE) is planned to detect and characterize such polarization signal. PIXIE will reach the confusion noise from the gravitational lensing E-mode signal and has the sensitivity and angular response to measure even the minimum predicted B-mode power spectrum at high statistical confidence. PIXIE will measure the CMB linear polarization to sensitivity of 70 nK per $1\,{\rm deg} \times 1\,{\rm deg}$ pixel, including the penalty for foreground subtraction. Averaged over the cleanest 75% of the sky, PIXIE can detect B-mode polarization to 3 nK sensitivity, well below the 30 nK predicted from large-field inflation models. The sensitivity is comparable to the "noise floor" of gravitational lensing, and allows robust detection of primordial gravity waves to limit $r < 10^{-3}$ at more than 5 standard deviations. In addition, PIXIE provides a critical test for keV dark-matter candidates: primordial dark matter annihilation distorts the CMB spectrum away from the blackbody shape with The resulting chemical potential

allows to determine the dark matter mass particle in the keV scale. PIXIE measurements of the y distortion determine the temperature of the intergalactic medium at reionization.

- Large-scale peculiar flows of clusters of galaxies provide an important test of the physics and initial conditions in the early Universe. On sufficiently large scales, $\gtrsim 100$ Mpc, this leads to a robust prediction of the amplitude and coherence length of these velocities independently of cosmological parameters or evolution of the Universe. One way to measure the peculiar velocities is from the kinematic component of the Sunyaev-Zeldovich (KSZ) effect: this had lead to measure a CMB KSZ dipole signal which is not from the primary CMB: this KSZ dipole implies a bulk flow of about 600-1,000 km/sec remaining coherent out to at least ~ 750 Mpc. (There may be a systematic overestimate smaller than 20% of this flow). The signal can be confirmed with the existing *public* cluster data in 5- and 7-yr WMAP data. These measurements do not agree with CDM structure formation. Perhaps, they are indicative of structures well beyond the present-day horizon left over from pre-inflationary epochs (as fast-roll). The *SCOUT* experiment (**S**unyaev-Zeldovich **C**luster **O**bservations as probes of the **U**niverse's **T**ilt) will catalog up to $\sim 2,000$ clusters extending to $z \sim 0.7$, double the depth of the measured flow and its accuracy and improve the current calibration uncertainties, upon application to forthcoming CMB data releases.

- Substantial observation efforts are being made to quantify both the statistical(number counts, correlations, spatial distributions...) and the internal properties (star formation histories, dark matter density profiles,...) of dSph galaxies. Recent discovery surveys have accentuated the **Satellite Problem** of CDM: Although some 25 dSph are now known assciated with each of the Milky way and M31, their numbers remain orders of magnitude too low compared to simple LCDM predictions. Further, the spatial distributions of these satellites are concentrated in sheets/groups, more so than is predicted. Dominant Baryonic Feedback on galaxy formation is required in LCDM to solve the Satellite Problem, and to reproduce something like the observed galaxy luminosity function. Feedback is not a free parameter, to be sub-grid fixed, but it is a consequence of the star formation rate, which is determinable from the chemical abundance distribution function of the earliest stars. Substantial progress is being made in quantifying the early histories of the local dSph: In all cases, *very low star formation rates are required by observation*. This implies : (i) **Very low baryonic feedback.** (ii) The field stars in the Milky Way were **not** formed in now tidally destroyed dSph. Appropriate high-resolution simulation efforts conclude that **baryon feedback does not affect DM structure** and that CDM still cannot produce realistic galaxies with realistic feedback and star formation recipes.

  Direct kinematic probing of dSph density profiles is making significant progress: Very precise kinematics for faint stars in dSph, and interestingly, the total mass enclosed within a half-light radius is a robust parameter. The existence of multiple populations inside a single dSph galaxy is used to determine the mass enclosed with the half-light radius of each population, thus providing several integrated mass determinations inside a single profile. This new kinematic and chemical abundance work has considerable potential to provide direct determinations of primordial DM-dominated density profiles.

- Cosmology and oscillation data show that at least one neutrino mass should be in the interval 0.04 - 0.30 eV. The smallness of this neutrino mass, which is realized in a seesaw mechanism, can be due to the existence of a large mass scale (as GUT scale). Lepton mixing may be explained by the tri-bimaximal mixing scheme (TBM). The issue of the existence of sterile neutrinos becomes crucial in the theory of neutrino masses and mixing. Both laboratory experiments and cosmological observations favour a 3+1 scheme with one sterile neutrino in the $\sim$eV scale.

- Sterile neutrinos with mass in the keV scale (1 to 10 keV) emerge as leading candidates for the dark matter (DM) particle from theory combined with astronomical observations.

  DM particles in the keV scale (warm dark matter, WDM) naturally reproduce (i) the observed galaxy structures at small scales (less than 50 kpc), (ii) the observed value of the galaxy surface density and phase space density (iii) the cored profiles of galaxy density profiles seen in astronomical observations.

  Heavier DM particles (as wimps in the GeV mass scale) do not reproduce the above important galaxy observations and run into growing and growing serious problems (they produce satellites problem, voids problem, galaxy size problem, unobserved density cusps and other problems).

  Minimal extensions of the Standard Model of particle physics include keV sterile neutrinos which are very weakly coupled to the standard model particles and are produced via the oscillation of the light (eV) active neutrinos,

with their mixing angle governing the amount of generated WDM. The mixing angle theta between active and sterile neutrinos should be in the 10^{-4} scale to reproduce the average DM density in the Universe.
Sterile neutrinos are necessarily produced out of thermal equilibrium. The production can be non-resonant (in the absence of lepton asymmetries) or resonantly ennhanced (if lepton asymmetries are present). The usual X ray bound together with the Lyman alpha bound forbids the non-resonant mechanism in the νMSM model.

- Warm Dark Matter particles feature a non-vanishing velocity dispersion which leads to a cutoff in the matter power spectrum as a consequence of free streaming. The essential ingredient is the distribution function of the WDM candidate solution of the collisionless Boltzmann equation from which the transfer function and power spectra are obtained. A WDM particle decoupled ultrarelativistic from the cosmological plasma has three evolution stages :the radiation dominated stages, when the particle is ultrarelativistic and then after when is non-relativistic, and the matter dominated stage. WDM sterile neutrinos produced non-resonantly via two different mechanisms yield very different distribution functions and power spectra which show two characteristic features: (i) a quasidegeneracy between the distribution function and the mass of the WDM particle (a less massive WDM candidate with a distribution function favoring low momenta has a power spectrum similar to that of a more massive particle but with a near thermal distribution function),(ii) the emergence of warm dark matter oscillations at scales of the order of the free streaming scale. Feature (i) suggests that constraints on the mass from the Lyman-α must be taken with a caveat since a reliable assessment requires knowledge of the distribution function, and feature (ii) suggests that typical power laws fits to the power spectra do not reliable describe small scales. Non-vanishing velocity dispersion and free streaming lead to a redshift dependence of the matter and velocity power spectra which affects peculiar velocities: Using the $z = 0$ power spectra for N-body simulations with initial conditions at large z incur in substantial errors underestimating the power spectrum of peculiar velocities.

  Sterile neutrinos with mass in the $\sim$ keV range are suitable warm dark matter candidates. These neutrinos can decay into an active-like neutrino and an X-ray photon. Abundance and phase space density of dwarf spheroidal galaxies constrain the mass to be in the $\sim$ keV range. Small scale aspects of sterile neutrinos and different mechanisms of their production were presented: The transfer function and power spectra are obtained by solving the collisionless Boltzmann equation during the radiation and matter dominated eras: as a consequence, the power spectra features new WDM acoustic oscillations on mass scales $\sim 10^8 - 10^9 \, M_\odot$.

- A right-handed neutrino of a mass of a few keV appears as the most interesting candidate to constitute dark matter. A consequence should be Lyman alpha emission and absorption at around a few microns; corresponding emission and absorption lines might be visible from molecular Hydrogen H_2 and H_3 and their ions, in the far infrared and sub-mm wavelength range. The detection at very high redshift of massive star formation, stellar evolution and the formation of the first super-massive black holes would constitute the most striking and testable prediction of this dark matter particle. This particle allows star formation very early, near redshift 80, and so also allows the formation of supermassive black holes by agglomerating massive stars; here merging starts at masses of a few million solar masses, ten percent of the baryonic mass in the initial DM clumps. This readily explains the supermassive black hole mass function. The formation of the first super-massive stars might be detectable among the point-source contributions to the fluctuations of the MWBG at very high wave-number (Atacama); their contribution is independent of z. The corresponding gravitational waves are not constrained by any existing limit, and could have given a substantial energy contribution at high z.

- Dark matter may be possibly visible (indirectly) via decay in odd properties of energetic particles and photons: The following discoveries have been reported: (i) an upturn in the CR-positron fraction, (ii) an upturn in the CR-electron spectrum, iii) a flat radio emission component near the Galactic Center (WMAP haze), iv) a corresponding IC component in gamma rays (Fermi haze and Fermi bubble), v) the 511 keV annihilation line also near the Galactic Center (Integral), and most recently, vi) an upturn in the CR-spectra of all elements from Helium (CREAM), with a hint of an upturn for Hydrogen, vii) A flat γ-spectrum at the Galactic Center (Fermi), and viii) have the complete cosmic ray spectrum available through 10^{15} to 10^{18} eV (KASCADE-Grande). All these features can be quantitatively well explained by the action of cosmic rays accelerated in the magnetic winds of very massive stars when they explode. This approach does not require any significant free parameters, it is older and simpler than adding Wolf Rayet-star supernova CR-contributions with pulsar wind nebula CR-contributions, and implies that Cen A is our highest energy physics laboratory accessible to direct observations of charged particles. All this allows with the galaxy data to derive the key properties of the dark matter particle: this clearly points to a keV mass particle (keV warm dark matter).

This particle has the advantage to allow star formation very early, near redshift 80, and so also allows the formation of supermassive black holes: they possibly formed out of agglomerating massive stars, in the gravitational potential well of the first DM clumps, whose mass in turn is determined by the properties of the DM particle. Black holes in turn also merge, but in this manner start their mergers at masses of a few million solar masses, about ten percent of the baryonic mass inside the initial dark matter clumps. This readily explains the supermassive black hole mass function . The formation of the first super-massive stars might be detectable among the point-source contributions to the fluctuations of the MWBG at very high wave-number (Atacama); their contribution is independent of redshift. The corresponding gravitational waves are not constrained by any existing limit, and could have given a substantial energy contribution at high redshift.

- All the observations of cosmic ray positrons and electrons and the like are due to normal astrophysical sources and processes, and do not require hypothetical decay or annihilation of heavy DM particles. The models of annihilation or decay of cold dark matter (wimps) become increasingly tailored and fine tuned to explain these normal astrophysical processes and their ability to survive observations is more and more reduced. Pulsar winds are perfect positron sources to power the positron excess. The spectra inferred from observations work fine. The data are expected to improve soon with AMS-02 to confirm that the positron excess is as pronounced as shown by Pamela. As a conclusion on this issue it appeared: "Let us be careful to get too excited about spectral features (positrons, nuclei,...): Some of these features also appear due to fluctuations in the source activity or locations. There is a lot of work to be done before we actually figure out the details of CR propagation and acceleration. Excesses should be compared with how well we understand such details. This is especially to be kept in mind when invoking unconventional explanations to CR excess, such as those based on cold dark matter annihilation. The CDM explanation to the positron excess was not the most natural: The signal from wimps is naturally too small but the theory was contrived (leptophilic DM, boost factors, Sommerfeld enhancement, ...) for the sole purpose of fitting one set of data (the positron fraction and the absence of antiproton anomalies)".

- Lyman-α constraints have been often misinterpreted or superficially invoked in the past to wrongly suggest on a tension with WDM, but those constraints have been by now clarified and relaxed, and such a tension does not exist: keV sterile neutrino dark matter (WDM) is consistent with Lyman-alpha constraints within a *wide range* of the sterile neutrino model parameters. **Only** for sterile neutrinos **assuming** a **non-resonant** (Dodelson-Widrow model) production mechanism, Lyman-alpha constraints provide a lower bound for the mass of about 4 keV. For thermal WDM relics (WDM particles decoupling at thermal equilibrium) the Lyman-alpha lower particle mass bounds are smaller than for non-thermal WDM relics (WDM particles decoupling out of thermal equilibrium). The number of Milky-Way satellites indicates lower bounds between 1 and 13 keV for different models of sterile neutrinos.

  WDM keV sterile neutrinos can be copiously produced in the supernovae cores. Supernova stringently constraints the neutrino mixing angle squared to be $\lesssim 10^{-9}$ for sterile neutrino masses $m > 100$ keV (in order to avoid excessive energy lost) but for smaller sterile neutrino masses the SN bound is not so direct. Within the models worked out till now, mixing angles are essentially unconstrained by SN in the favoured WDM mass range, namely $1 < m < 10$ keV. Mixing between electron and keV sterile neutrinos could help SN explosions, case which deserve investigation.

- The possibility of laboratory detection of warm dark matter is extremely interesting. Only a direct detection of the DM particle can give a clear-cut answer to the nature of DM and at present. At present, only the **Katrin and Mare experiments** have the possibility to do that for sterile neutrinos. **Mare** bounds on sterile neutrinos are placed from the beta decay of Re187 and EC decay of Ho163, **Mare** keeps collecting data in both. The possibility that **Katrin** experiment can look to sterile neutrinos in the tritium decay was discussed. Katrin experiment have the potentiality to detect warm dark matter if its set-up would be adapted to look to keV scale sterile neutrinos. KATRIN experiment concentrates its attention right now on the electron spectrum near its end-point since its goal is to measure the active neutrino mass. Sterile neutrinos in the tritium decay will affect the electron kinematics at an energy about m below the end-point of the spectrum (m = sterile neutrinos mass). KATRIN in the future could perhaps adapt its set-up to look to keV scale sterile neutrinos. It will be a a fantastic discovery to detect dark matter in a beta decay.

- Astronomical observations strongly indicate that **dark matter halos are cored till scales below 1 kpc**. More precisely, the measured cores **are not** hidden cusps. CDM Numerical simulations -with wimps (particles

heavier than 1 GeV)- without **and** with baryons yield cusped dark matter halos. Adding baryons do not alleviate the problems of wimps (CDM) simulations, on the contrary adiabatic contraction increases the central density of cups worsening the discrepancies with astronomical observations. In order to transform the CDM cusps into cores, the baryon+CDM simulations need to introduce strong baryon and supernovae feedback which produces a large star formation rate contradicting the observations. None of the predictions of CDM simulations at small scales (cusps, substructures, ...) have been observed. The discrepancies of CDM simulations with the astronomical observations at small scales $\lesssim$ 100 kpc **is staggering**: satellite problem (for example, only 1/3 of satellites predicted by CDM simulations around our galaxy are observed), the surface density problem (the value obtained in CDM simulations is 1000 times larger than the observed galaxy surface density value), the voids problem, size problem (CDM simulations produce too small galaxies).

- The use of keV scale WDM particles in the simulations instead of the GeV CDM wimps, alleviate all the above problems. For the core-cusp problem, setting the velocity dispersion of keV scale DM particles seems beyond the present resolution of computer simulations. However, the velocity dispersion is negligible for $z < 20$ where the non-linear regime and structure formation starts. Analytic work in the linear approximation produces cored profiles for keV scale DM particles and cusped profiles for CDM. Model-independent analysis of DM from phase-space density and surface density observational data plus theoretical analysis points to a DM particle mass in the keV scale. The dark matter particle candidates with high mass (100 GeV, 'wimps') are strongly disfavored, while cored (non cusped) dark matter halos and warm (keV scale mass) dark matter are strongly favoured from theory and astrophysical observations. As a conclusion, the dark matter particle candidates with large mass ($\sim$ 100 GeV, the so called 'wimps') are strongly disfavored, while light (keV scale mass) dark matter are being increasingly favoured both from theory, numerical simulations and a wide set of astrophysical observations.

- Recent ΛWDM N-body simulations have been performed by different groups. High resolution simulations for different types of DM (HDM, WDM or CDM), allow to visualize the effects of the mass of the corresponding DM particles: free-streaming lentgh scale, initial velocities and associated phase space density properties: for masses in the eV scale (HDM), halo formation occurs top down on all scales with the most massive haloes collapsing first; if primordial velocities are large enough, free streaming erases all perturbations and haloes cannot form (HDM). The concentration-mass halo relation for mass of hundreds eV is reversed with respect to that found for CDM wimps of GeV mass. For realistic keV WDM these simulations deserve investigation: it could be expected from these HDM and CDM effects that combined free-streaming and velocity effects in keV WDM simulations could produce a bottom-up hierarchical scenario with the right amount of sub-structures (and some scale at which transition from top-down to bottom up regime is visualized).

  Moreover, interestingly enough, recent large high resolution ΛWDM N-body simulations allow to discriminate among thermal and non-thermal WDM (sterile neutrinos): Unlike conventional thermal relics, non-thermal WDM has a peculiar velocity distribution (a little skewed to low velocities) which translates into a characteristic linear matter power spectrum decreasing slower across the cut-off free-streaming scale than the thermal WDM spectrum. As a consequence, the radial distribution of the subhalos predicted by WDM sterile neutrinos remarkably reproduces the observed distribution of Milky Way satellites in the range above $\sim$ 40 kpc, while the thermal WDM supresses subgalactic structures perhaps too much, by a factor $2 - 4$ than the observation. Both simulations were performed for a mass equal to 1 keV. Simulations for a mass larger than 1 keV (in the range between 2 and 10 keV, say) should still improve these results.

- The effect of keV WDM can be also observable in the statistical properties of cosmological Large Scale Structure. Cosmic shear (weak gravitational lensing) does not strongly depend on baryonic physics and is a promising probe. First results in a simple thermal relic scenario indicate that future weak lensing surveys could see a WDM signal for $m_{WDM} \sim 2$ keV or smaller. The predicted limit beyond which these surveys will not see a WDM signal is $m_{WDM} \sim 2.5$ keV (thermal relic) for combined Euclid + Planck. More realistic models deserve investigation and are expected to relaxe such minimal bound. With the real data, the non-linear WDM model should be taken into account.

  The predicted galaxy distribution in the local universe for ΛWDM (ie, CLUES numerical simulations with warm dark matter of mass of $m_{\mathrm{WDM}} = 1$ keV) well reproduces the observed one in the ALFALFA survey. On the contrary, the ΛCDM model predicts a steep rise in the velocity function towards low velocities and thus forecasts much more sources both in Virgo-direction as well as in anti-Virgo-direction than the ones observed

by the ALFALFA survey. These results add problems for CDM, also the spectrum of mini-voids points to a problem of the ΛCDM model. The ΛWDM model provides a natural solution to this problem.

- An 'Universal Rotation Curve' (URC) of spiral galaxies emerged from 3200 individual observed Rotation Curves (RCs) and reproduces remarkably well out to the virial radius the Rotation Curve of any spiral galaxy. The URC is the observational counterpart of the circular velocity profile from cosmological simulations. CDM numerical simulations give the NFW cuspy halo profile. A careful analysis from about 100 observed high quality rotation curves has now **ruled out** the disk + NFW halo mass model, in favor of **cored profiles**. The observed galaxy surface density (surface gravity acceleration) appears to be universal within $\sim 10\%$ with values around $100\ M_\odot/\mathrm{pc}^2$, irrespective of galaxy morphology, luminosity and Hubble types, spanning over 14 magnitudes in luminosity and mass profiles determined by several independent methods.

- Interestingly enough, a constant surface density (in this case column density) with value around $120\ M_\odot/\mathrm{pc}^2$ similar to that found for galaxy systems is found too for the interstellar molecular clouds, irrespective of size and compositions over six order of magnitude; this universal surface density in molecular clouds is a consequence of the Larson scaling laws. This suggests the role of gravity on matter (whatever DM or baryonic) as a dominant underlying mechanism to produce such universal surface density in galaxies and molecular clouds. Recent re-examination of different and independent (mostly millimeter) molecular cloud data sets show that interestellar clouds do follow Larson law $Mass \sim (Size)^2$ exquisitely well, and therefore very similar projected mass densities at each extinction threshold. Such scaling and universality should play a key role in cloud structure formation.

- A key part of any galaxy formation process and evolution involves dark matter. Cold gas accretion and mergers became important ingredients of the CDM models but they have little observational evidence. DM properties and its correlation with stellar masses are measured today up to $z = 2$; at $z > 2$ observations are much less certain. Using kinematics and star formation rates, all types of masses -gaseous, stellar and dark- are measured now up to $z = 1.4$. The DM density within galaxies declines at higher redshifts. Star formation is observed to be more common in the past than today. More passive galaxies are in more massive DM halos, namely most massive DM halos have lowest fraction of stellar mass. CDM predicts high overabundance of structure today and under-abundance of structure in the past with respect to observations. The size-luminosity scaling relation is the tightest of all purely photometric correlations used to characterize galaxies; its environmental dependence have been highly debated but recent findings show that the size-luminosity relation of nearby elliptical galaxies is well defined by a fundamental line and is environmental independent. Observed structural properties of elliptical galaxies appear simple and with no environmental dependence, showing that their growth via important mergers -as required by CDM galaxy formation- is not plausible. Moreover, observations in brightest cluster galaxies (BCGs) show little changes in the sizes of most massive galaxies since $z = 1$ and this scale-size evolution appears closer to that of radio galaxies over a similar epoch. This lack of size growth evolution, a lack of BCG stellar mass evolution is observed too, demonstrates that major merging is not an important process. Again, these observations put in serious trubble CDM 'semianalytical models' of BCG evolution which require about 70% of the final BCG stellar mass to be accreted in the evolution and important growth factors in size of massive elliptical massive galaxies.

- The sun seismic model allows a prediction of the gravity mode frequencies that are in very good agreement with the first observation of dipole gravity modes. Their period differences are smaller than 0.3 minute. It also produces results in agreement with the detection of all the different neutrino installations . So the central temperature, central density and core density profile of the Sun must be very near from those of the seismic model predictions, even the detailed physics of the radiative zone is not totally under control: possible existence of a fossil field, possible bad determination of the transfer of energy, possible effect of dark matter. The new solar detections cannot constrain cold dark matter annihilation models as the estimated cross section is too small to produce any effect on the density profile. The presence of non-annihilating WIMPs in the Sun for masses $\leq$ 10 GeV and spin dependent cross sections $> 5\,10^{-36}$ cm^2 is excluded. No signature is visible in the obtained profile in the solar core. The seismic model has a central temperature higher than the standard solar model (SSM), (T$_C$= 15.51, SSM neutrino prediction is not compatible with boron neutrino detection), but a density slightly smaller by 2 or 3%. This remark could favor other kinds of processes like a different gravitational effect due to WDM (sterile neutrinos ?) acting on the whole radiative zone. The radiative zone is certainly more complex than thought previously: a good energetic balance and all the potential dynamical effects need to be

included before any conclusion on this subject. In the coming years helio- and asteroseismology will provide complementary results to extend these studies and to check these probes of dark matter.

- *As an overall conclusion*, CDM represents the past and WDM represents the future in the DM research. 20 year old CDM research, namely: CDM simulations and their proposed baryonic solutions, and the CDM wimps candidates (~ 100 GeV, the so called 'wimps') are strongly pointed out by the galaxy observations as the *wrong* solution to DM. Theoretically, and placed in perspective after more than 20 years, the reason why CDM does not work appears simple and clear to understand and directly linked to the excesively heavy and slow CDM wimp, which determines an excessively small (for astrophysical structures) free streaming length, and unrealistic overstructure at these scales. On the contrary, new keV WDM research, keV WDM simulations, and keV scale mass WDM particles are strongly favoured by galaxy observations and theoretical analysis, they naturally *work* and agree with the astrophysical observations at *all* scales, (galactic as well as cosmological scales). Theoretically, the reason why WDM works so well is clear and simple, directly linked to the keV scale mass and velocities of the WDM particles, and free-streaming length. The experimental search for serious WDM particle candidates (sterile neutrinos) appears urgent and important: it will be a fantastic discovery to detect dark matter in a beta decay. There is a formidable WDM work to perform ahead of us, these highlights point some of the directions where it is worthwhile to put the effort.

C. The present context and future in Dark Matter and Galaxy Formation research.

- Facts and status of DM research: Astrophysical observations point to the existence of DM. Despite of that, proposals to replace DM by modifing the laws of physics did appeared, however notice that modifying gravity spoils the standard model of cosmology and particle physics not providing an alternative. After more than twenty active years the subject of DM is mature, (many people is involved in this problem, different groups perform N-body cosmological simulations and on the other hand direct experimental particle searches are performed by different groups, an important number of conferences on DM and related subjects is held regularly). DM research appears mainly in three sets: (a) Particle physics DM model building beyond the standard model of particle physics, dedicated laboratory experiments, annhilating DM, all concentrated on CDM and CDM wimps. (b) Astrophysical DM: astronomical observations, astrophysical models. (c) Numerical CDM simulations. The results of (a) and (b) do not agree and (b) and (c) do not agree neither at small scales. None of the small scale predictions of CDM simulations have been observed: cusps and over abundance of substructures differ by a huge factor with respect to those observed. In addition, all direct *dedicated* searchs of CDM wimps from more than twenty years gave *null results. Something is going wrong in the CDM research and the right answer is: the nature of DM is not cold (GeV scale) but warm (keV scale).*

- Many researchers continue to work with heavy CDM candidates (mass $\gtrsim 1$ GeV) despite the **staggering** evidence that these CDM particles do not reproduce the small scale astronomical observations ($\lesssim 100$ kpc). Why? [It is known now that the keV scale DM particles naturally produce the observed small scale structure]. Such strategic question is present in many discussions, everyday and off of the record (and on the record) talks in the field. The answer deals in large part with the inertia (material, intellectual, social, other, ...) that structured research and big-sized science in general do have, which involve huge number of people, huge budgets, longtime planned experiments, and the 'power' (and the conservation of power) such situation could allow to some of the research lines following the trend; as long as budgets will allow to run wimp experimental searches and CDM simulations such research lines could not deeply change, although they would progressively decline.

  Notice that in most of the DM litterature or conferences, wimps are still 'granted' as "the" DM particle, and CDM as "the" DM; is only recently that the differences and clarifications are being clearly recognized and acknowledged. While wimps were a testable hypothesis at the beginning of the CDM research, one could ask oneself why they continue to be worked out and 'searched' experimentally in spite of the strong astronomical and astrophysical evidence against them.
  Similar situations (although do not such extremal as the CDM situation) happened in other branches of physics and cosmology: Before the CMB anisotropy observations, the issue of structure formation was plugged with several alternative proposals which were afterwards ruled out. Also, string theory passed from being considered "the theory of everything" to "the theory of nothing" (as a physical theory), as no physical experimental evidence have been obtained and its cosmological implementation and predictions desagree with observations. (In despite of all that, papers on such proposals continue -and probably will continue- to appear. But is clear that big

dedicated experiments are not planned or built to test such papers). In science, what is today 'popular' can be discarded afterwards; what is today 'new' and minoritary can becomes 'standard' and majoritarily accepted if verified experimentally.

"Things are beginning to hang together, and we can now make quite specific predictions as a consequence of the keV DM model. If the right-handed neutrino were this particle, star formation and the first super-massive black holes could be formed quite early, possibly earlier than redshift 50. A confirmation would be spectacular."

[Peter Biermann, his conclusion of the 14th Paris Cosmology Colloquium Chalonge 2010 in 'Live minutes of the Colloquium', arXiv:1009.3494].

"Examine the objects as they are and you will see their true nature; look at them from your own ego and you will see only your feelings; because nature is neutral, while your feelings are only prejudice and obscurity."

[Gerry Gilmore quoting Shao Yong, 1011-1077 in the 14th Paris Cosmology Colloquium Chalonge 2010 http://chalonge.obspm.fr/Programme_Paris2010.html, arXiv:1009.3494].

"Let us be careful to get too excited about spectral features (positrons, nuclei,...): This is especially to be kept in mind when invoking unconventional explanations to CR excess, such as those based on cold dark matter annihilation. The CDM explanation to the positron excess was not the most natural: The signal from wimps is naturally too small but the theory was contrived (leptophilic DM, boost factors, Sommerfeld enhancement, ...) for the sole purpose of fitting one set of data (the positron fraction and the absence of antiproton anomalies)."

[Pasquale Blasi, his conclusion in his Lecture at the 15th Paris Cosmology Colloquium Chalonge 2011.]

The Lectures of the Colloquium can be found at:

http://chalonge.obspm.fr/ProgrammeParis2011.html

The photos of the Colloquium can be found at:

http://chalonge.obspm.fr/album2011/album/index.html

The photos of the Open Session of the Colloquium can be found at:

http://chalonge.obspm.fr/albumopensession2011/index.html

Best congratulations and acknowledgements to all lectures and participants which made the 15th Paris Cosmology Colloquium 2011 so fruitful and interesting, the Ecole d'Astrophysique Daniel Chalonge looks forward to you for the next Colloquium of this series:

The 16th Paris Cosmology Colloquium 2012 devoted to

THE NEW STANDARD MODEL OF THE UNIVERSE: LAMBDA WARM DARK MATTER (ΛWDM) THEORY AND OBSERVATIONS

Observatoire de Paris, historic Perrault building, 25, 26, 27 JULY 2012.

http://www.chalonge.obspm.fr/colloque2012.html

IX.   PHOTOS OF THE COLLOQUIUM

Photos of the Colloquium are available at:

http://www.chalonge.obspm.fr/colloque2011.html

FIG. 17: Discussion time during a session of the Chalonge School atthe Salle Cassini

FIG. 18: At the Salle Cassini

X.   LIST OF PARTICIPANTS

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FIG. 19: Open Session of the Chalonge School at the Salle Cassini

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CNUDDE Sylvain, LESIA Observatoire de Paris, Meudon, France

FIG. 20: Champagne at the Salle du Conseil

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FIG. 21: Coffee break at the Salle du Conseil

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